MSC Nastran 2022.4

Aeroelastic Analysis User's Guide

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Preface

About this Book

This guide attempts to describe the practical aspects of aeroelastic analysis that are required to obtain design and certification data. It is not intended to be a textbook, although it does contain certain theoretical material not found in available textbooks. The primary purpose of the theoretical material is to support the applications. The text is not completely self-contained because it relies extensively upon information described in the *MSC Nastran Linear Static Analysis User's Guide* and the *MSC Nastran Dynamic Analysis User's Guide*, as well as the *MSC Nastran Quick Reference Guide,* to obtain solutions with a finite element model. The program modules used in the aeroelastic analyses are documented in the *MSC Nastran Programmer's Manual*.

List of MSC Nastran Guides

A list of some of the MSC Nastran guides is as follows:

Installation and Release Guides
■ Installation and Operations Guide
■ Release Guide
Reference Guides
■ Quick Reference Guide
■ DMAP Programmer's Guide
■ Reference Guide
■ Utilities Guide
■ Getting Started Guide
■ SOL 400 Getting Started Guide
■ MSC Nastran DMAP Errors User Guide
Demonstration Guides
■ Linear Analysis
■ Implicit Nonlinear (SOL 400)
■ Explicit Nonlinear (SOL 700)
■ MSC Nastran Verification Guide
User's Guides
■ Automated Component Modal Synthesis (ACMS)
■ Access Manual
■ Aeroelastic Analysis
■ Design Sensitivity and Optimization
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- Embedded Fatigue
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- Linear Static Analysis
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Using other Manuals

After reading the *Getting Started Guide*, we recommend that you go through either the *Linear Static Analysis User's Guide*, the *Dynamic Analysis User's Guide*, or the *Nonlinear User's Guide* depending on the type of simulation you are interested in performing. Details of some of the manuals are listed here for your reference.

This guide contains many excerpts from the *Quick Reference Guide (QRG)*. Most of the excerpts have been edited-some extensively-to eliminate material that is not relevant to the topics covered in this book.

- MSC Nastran Quick Reference Guide: The *QRG* contains a complete description of all the input entries for MSC Nastran. It contains complete descriptions of all the finite element input data and options available in MSC Nastran. Each entry provides a description, formats, examples, details on options, and general remarks. You will find the full descriptions for all SOL 400 input entries in the *QRG*.
- MSC Nastran Reference Guide: It provides supporting information that relates to the theory of MSC Nastran inputs, element libraries, and loads and boundary conditions.
- Dynamic Analysis User's Guide: This guide describes the proper use of MSC Nastran for solving various dynamic analysis problems. This guide serves as both an introduction to dynamic analysis for the new user and a reference for the experienced user.
- DMAP Programmer's Guide: It provides example problems and includes description of the input, procedures, and results information that relates to the practical use of the MSC Nastran inputs, element libraries, and loads and boundary conditions.

Typographical Conventions

To distinguish special uses of words, we use certain typographic conventions. This section provides overview of the typographical conventions used in the document.

This section describes some syntax that will help you in understanding text in the various chapters and thus in facilitating your learning process. It contains stylistic conventions to denote user action, to emphasize particular aspects of a MSC Nastran run or to signal other differences within the text.

Courier New	Represents command-line options of MSC Nastran and results from `f04/f06` files. Example: `nast20224 memorymax=16gb myjob.dat`
Quoted Text	Represents command-line options of MSC Nastran for in-line text. Example: memorymax=16gb
Arial font	To represent elements. Example: `RBE3` and `RSPLINE` are interpolation elements and are not rigid.
Red Text	Represents items in the examples that we want to emphasize. Example: smp=16
Bold Text	Represents items in the text that we want to emphasize. Example: **dmp=4**
Italic Text	Represents references to manuals/documents. Example: *MSC Nastran Quick Reference Guide*

Note:	As MSC Nastran does not have a User Interface, we use bold text to emphasize particular information. For the products that have User Interface (UI), typically Bold text is used to mention UI entities.

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Clients frequently call up the support engineers at Hexagon with enquiry regarding models that do not run correctly. Our technical support staff can help you much more efficiently and effectively if you are working with a small model, since debugging a small model is much easier, and the turnaround time to rerun a (hopefully) corrected test model is minutes rather than hours.

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This section describes how to access the MSC Nastran documentation outside of Hexagon. MSC Nastran documentation is available through PDF files. The PDF files can be obtained from the following sources:

- MSC Nastran documentation installer
- SimCompanion
- Combined documentation

The PDF documentation files are appropriate for viewing and printing with Adobe Acrobat Reader (version 10.1.4 or higher), which is available for most Windows and Linux systems. These files are identified by a .pdf suffix in their file names.

Downloading the PDF Documentation Files

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Printing the PDF Files

Adobe Acrobat PDF files are provided for printing all or part of the manuals. You can select the paper size to which you are printing in Adobe Acrobat Reader by doing the following:

1. Click **File**.
2. Select the **Print**.... option. The **Print** dialog box is displayed.
3. Select **Page Setup**....
4. Choose the required paper size in the **Page Setup** menu.

The PDF files are recommended when printing long sections since the printout will have a higher quality.

If the page is too large to fit on your paper size, you can reduce it by doing the following:

1. Select the **File** -> **Print**.
2. Under **Page Scaling,** choose the **Shrink to Printable Area** option.

1 Introduction

The *MSC Nastran Aeroelestic Analysis User's Guide* describes the theoretical aspects and the numerical techniques used to perform aeroelastic analyses with MSC Nastran.

Overview of Aeroelastic Analysis

The aeroelastic analyses described in this guide use the following features:

- You can use any of the existing MSC Nastran structural finite elements (except axisymmetric elements) to build the structural model. The structural stiffness, mass, and damping matrices required by the aeroelastic analyses are generated by MSC Nastran from the user input of geometric, structural, inertial, and damping data, for subsequent use in the various aeroelastic analyses.
- Matrices of aerodynamic influence coefficients are computed from the data describing the geometry of the aerodynamic finite elements. The choice of aerodynamic grid points for the aerodynamic model is independent of the location of the structural grid points. One subsonic and three supersonic lifting surface aerodynamic theories are available in MSC Nastran, as well as Strip Theory. The subsonic theory is the Doublet-Lattice method, which can account for interference among multiple lifting surfaces and bodies. The supersonic theories are the Mach Box method, Piston Theory, and the ZONA51 method for multiple interfering lifting surfaces that was added to MSC Nastran.
- An automated interpolation procedure is provided to relate the aerodynamic to the structural degrees of freedom. Splining techniques for both lines and surfaces are used to generate the transformation matrix from structural grid point deflections to aerodynamic grid point deflections where local streamwise slopes are also computed. The transpose of this matrix transfers the aerodynamic forces and moments at aerodynamic boxes to structural grid points.
- The structural load distribution on an elastic vehicle in trimmed flight is determined by solving the equations for static equilibrium. The solution process leads to aerodynamic stability derivatives, for example, lift and moment curve slopes and lift and moment coefficients due to control surface rotation, and trim variables, for example, angle of attack and control surface setting, as well as aerodynamic and structural loads, structural deflections, and element stresses.

  The analysis at subsonic speeds utilizes the Vortex-Lattice aerodynamic theory (that is, the steady case of the Doublet-Lattice method); the analysis at supersonic speeds uses the ZONA51 aerodynamic theory at zero reduced frequency. Control surface reversal speeds can be obtained by interpolation of roll control effectiveness, C_{l_δ}, versus flight dynamic pressure. Static divergence speeds can be obtained.
- The number of degrees of freedom required for accurate solutions to dynamic aeroelastic problems is generally far less than the number of physical degrees of freedom used in the finite element structural model. The number of independent degrees of freedom can be greatly reduced by using the (complex) amplitudes of a series of vibration modes as generalized coordinates, for example, by Galerkin's method. MSC Nastran has the capability to compute the vibration modes and frequencies and to make the transformation to modal coordinates. The matrices of aerodynamic influence coefficients are also transformed to generalized aerodynamic forces by use of the vibration eigenvectors.
- The dynamic aeroelastic stability problem, flutter, is solved by any of three methods.

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- **The K-method**: Sometimes referred to as the American Method.
- **The KE-method**: It is more efficient from the point of view of tracking roots, but is limited in input (no viscous damping) and output (no eigenvectors).
- **The PK-method:** It is similar to the British flutter method, which was developed by the Royal Aircraft Establishment.

- The capability to couple servo-systems with the structure and the presence of aerodynamic forces enables aeroservoelastic analysis of stability augmentation or load alleviation systems.
- Analyses of frequency response to arbitrarily specified forcing functions can be carried out using the oscillatory aerodynamic loads from any of the available aerodynamic theories. Frequency response to a harmonic gust field can be calculated at subsonic speeds using the Doublet-Lattice method for wing/body interference, and by the ZONA51 method for interfering lifting surfaces at supersonic speeds.
- Because unsteady aerodynamic loads are obtained only for steady-state harmonic motion, they are known only in the frequency- and not the time-domain. Inverse Fourier Transform techniques provide the appropriate methods by which transient response is obtained from the frequency response. Both forward and inverse Fourier transforms are provided so that the time-varying forcing function or the gust profile can be transformed into the frequency domain. Then, after convolution with the system frequency response, the inverse transform leads to the transient response of the system to the specified forcing function or gust profile.
- Stationary random response depends on the frequency response of the system to a specified loading and the power spectral density of that loading. The loading may be either a specified force distribution or a harmonic gust field. The statistical quantities of interest in the response are $\bar{A}$, the ratio of standard deviations (rms values) of the response to that of the input loading, and N_0 , the mean frequency of zero crossings (with a positive slope) of the response.
- The sensitivities of response parameters to changes in design variables are calculated by the perturbation techniques developed for structural optimization in MSC Nastran and extended to include static aeroelasticity and flutter. The basic aeroelastic sensitivities that can be obtained include stability derivatives, trim variables, and flutter system dampings. The synthetic response technique of MSC Nastran optimization also permits the calculation of sensitivities of user-specified functions of those standard response quantities.
- Optimization of aeroelastic characteristics can be combined with the other optimization features of MSC Nastran in SOLution 200, and vehicles can be designed optimally for aeroelastic loads, flying qualities, and flutter, as well as for strength, vibration frequencies, and buckling characteristics.

Display of Results

The output file from aeroelastic analyses contains the usual displacement, stress, force, etc. results from a MSC Nastran analysis. There is also output of specialized aeroelastic results such as stability derivatives, trim results and flutter summaries. The results are more readily viewed in a graphical user interface such as MSC Patran. The MSC Flightloads software (MSC Flightloads and Dynamics User’s Guide) provides specialized pre- and post-processing support for aeroelasticity.

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Aeroelastic Problems

A large number of problems is necessary to illustrate the principal features of the aeroelastic capability of MSC Nastran. The analyses can be grouped under four headings:

- **Static aeroelasticity**: Five static aeroelastic problems illustrate the symmetric, antisymmetric, and unsymmetric options.
- **Dynamic stability (flutter)**: Flutter analyses by the three available flutter methods have then been variously selected to demonstrate all of the available aerodynamic theories.
- **Dynamic response**: Examples of transient, frequency, and random responses are chosen as applications of the dynamic response analysis.
- **Design sensitivity and optimization**: A small example is considered first for its design sensitivities and is then optimized for a variety of constraints on deflections, strength, and aeroelastic characteristics.

A physical description of each problem, along with its finite element model, is provided. A discussion of the results of each analysis is presented. Limited MSC Nastran output is also presented for each example, including the input data echo and highlights of the calculated results.

The seven-character identification used in the Test Problem Library (TPL) is adopted for the example problems. The notation used here is HAXXXYZ where HA denotes *Handbook for Aeroelastic Analysis* [the title of the prior MSC user document on aeroelasticity, see Rodden (1987) [Reference 43]].

- XXX denotes the Solution Sequence number (144, 145, 146 or 200)
- Y is a letter denoting the specific example for a given Solution Sequence.
- Z, if used, denotes a specific feature of the example, for example, R denotes a restart.

To access the sample problems in the TPL, follow the instructions in **Section 3.9** of the *MSC Nastran Installation and Operation Instructions* for your system. The problems have been placed in the *aero_ss* subdirectory of the TPL.

Note:	You should realize that real number results could change slightly when the test problems are run with a different operating system and/or a different version of MSC Nastran than was used when generating the results shown in this guide. There may be cases where formats have changed so that the output can have a somewhat difference appearance than what is shown in the guide, but the intent is to present results that are up-to-date.

2 Aeroelastic Analysis with MSC Nastran

Introduction to Aeroelastic Analysis and Design

Aeroelastic Modules and DMAP Sequences

Aeroelastic analysis and design solution sequences extend the range of capabilities in MSC Nastran beyond basic static and dynamic structural analysis. Modules are available to:

- Generate aerodynamic grid points
- Compute aerodynamic matrices
- Convert User Defined Aerodynamic Input into appropriate aerodynamic matrices
- Provide connection (interpolation) between the structural and aerodynamic grid points
- Solve the equations for static aeroelasticity
- Solve the equations for flutter
- Solve the equations for dynamic aeroelastic response
- Calculate aeroelastic design sensitivities
- Optimize aeroelastic and related structural characteristics

Four DMAP sequences are available, one each for:

- static aeroelastic analyses
- modal flutter analyses
- modal dynamic aeroelastic response analyses
- design sensitivity and optimization including aeroelastic effects

The fourth sequence has applications to many areas other than aeroelasticity, this guide presents only design sensitivity and optimization information as it relates to aeroelasticity. For comprehensive details, refer to the *MSC.Nastran Design Sensitivity and Optimization User's Guide*.

The Aerodynamic Finite Element Model

MSC Nastran aerodynamic analysis, like structural analysis, is based upon a finite element approach. Methods are available in the code for generating the aerodynamics (internal methods) or for importing results from another code (external methods) This Guide emphasizes the internal method, but discusses the external methods as well. For the internal methods, the finite aerodynamic elements are strips or boxes on which there are aerodynamic forces. The aerodynamic elements, even for complex vehicles, must be in regular arrays. In particular, the aerodynamic elements for the lattice methods are arrays of trapezoidal boxes with sides that are parallel to the airflow. These can be described simply by defining properties of the array (panel). The external methods do not require regular arrays and the aerodyanmic mesh can be more general. For both internal and external aerodynamics, the grid points defining the structure usually do not coincide with the grid points defining the aerodynamic elements. For this reason, provision has been made to generate equations for interpolating between the two. This interpolation is a key feature since it allows the choice of structural and aerodynamic elements to be based upon structural and aerodynamic considerations independently.

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Oscillatory Aerodynamics

Unsteady aerodynamic forces are generated when the flow is disturbed by the moving structure, or, as in the case of atmospheric turbulence, when the flow itself is unsteady. In the former case, theory leads to a matrix that relates the forces acting upon the structure due to the deflections of the structure. Methods that involve interactions among aerodynamic elements are available in MSC Nastran only for steady-state sinusoidal motion. Phase lags occur between the motions and the forces; thus, the elements of the matrices are complex numbers. Furthermore, these complex influence coefficient matrices depend upon two parameters of the flow: reduced frequency (dimensionless ratio of frequency to velocity) and Mach number (ratio of velocity to speed of sound). Such matrices, if computed by interaction theories such as the Doublet-Lattice or ZONA51 methods, are relatively expensive to generate. An effective method to evaluate the matrices for a large number of parameter values is to compute the matrices for a few selected values and to interpolate to the remaining values. This parametric interpolation is an automatic feature of the solution modules for aeroelastic analysis.

Note that aerodynamic analysis with Mach number >0 implies that the flow is compressible.

In the case of atmospheric turbulence, theory leads to the forces on the structure in terms of the spectral composition of the turbulence, as well as the frequency response of the structure in a harmonic gust field. The turbulence spectrum and frequency response can be used to generate the power spectra of selected responses and their statistical properties.

Aeroelastic Sensitivity and Optimization

The sensitivities of aeroelastic responses require manipulating the equations used to perform the aeroelastic analysis while perturbing structural parameters, such as element areas and thicknesses. The result is a prediction of the change in a particular response, such as a stability derivative, due to a change in the parameter. This is useful in its own right to allow the user to gain insight into the aeroelastic design task and to make changes in the design in a systematic fashion. This capability is particularly useful in aeroelastic analyses since the aerodynamic effects interact with the structural stiffness and inertial properties in an often nonintuitive fashion. The sensitivities are most useful when coupled with the MSC Nastran optimization capability. Here, the user specifies design goals (such as minimum weight) and restrictions (such as no flutter within the flight envelope), and the MSC Nastran optimization procedure alters the design in order to meet these requirements. Because the aeroelastic optimization capability has been linked to the existing optimization capability, the design process can include requirements on nonaeroelastic factors such as a normal modal frequency or a stress response to a statically applied load that does not include aeroelastic effects.

Aerodynamic Data Input and Generation

Aerodynamic elements are strips, boxes, or segments of bodies that are combined to idealize the vehicle for the computation of aerodynamic forces. These elements, like structural elements, are defined by their geometry and their motions are defined by degrees of freedom at aerodynamic grid points. Requirements of the aerodynamic theory often dictate the geometry of the boxes. For example, the Mach Box method (MBM) uses only rectangular boxes, whereas the Doublet-Lattice (DLM) and ZONA51 methods assume trapezoidal boxes with their edges parallel to the free-stream velocity. By the use of aerodynamic input data, aerodynamic elements and grid points are automatically generated to help ensure that many of the theoretical requirements are met.

Aerodynamic Coordinate Systems

Aerodynamic calculations are performed using a Cartesian coordinate system. By the usual convention, the flow is in the positive x-direction, and the x-axis of every internal aerodynamic element must be parallel to the flow in its undeformed position. (This is an assumption of aerodynamic small disturbance theory.) The structural coordinate systems may be defined independently, since the use of the same system for both may place an undesirable restriction upon the description of the structural model. Any MSC Nastran Cartesian system may be specified for the aerodynamic coordinates, as long as the flow is defined in the direction of the x-axis. All aerodynamic element and grid point data are transformed to the aerodynamic coordinate system. All the global (displacement) coordinate systems of the aerodynamic grid points will have their T1-directions in the flow direction.

Aerodynamic Grid Points

The aerodynamic grid points are physically located at the centers of the boxes for the lifting surface theories, at the centers of body elements for the DLM, at the quarter-chord/midspan point of the strips for Strip Theory and Piston Theory, and at user-defined points for the Mach Box method. Permanent constraints are generated for the unused degrees of freedom. A second set of grid points, used only for undeformed plotting, is located at the element corners. Grid point numbers are generated based upon the element identification number. For any panel, the box numbers start with the panel identification number and increase consecutively.

Aerodynamic Degrees of Freedom

Aerodynamic degrees of freedom, along with any extra points, are in addition to structural degrees of freedom. This introduces the following displacement sets for aeroelasticity:

$$\left.\begin{array}{l} u_k \\ \\ \left.\begin{array}{l} u_{sa} \\ \\ u_p \end{array}\right\} u_{ps} \end{array}\right\} u_{pa}$$

u_k		Aerodynamic degrees of freedom at which aerodynamics are computed
u_{sa}		Permanently constrained degrees of freedom associated with aerodynamic grid points
		Aerodynamic degrees of freedom at which control points are located

u_{ps}	Union of u_p (physical) and u_{sa}
u_{pa}	Union of u_k and u_{ps} (physical and aerodynamic)

The set u_{pa} replaces u_p as the set available for output at grid, scalar, and extra points.

For static aeroelasticity, the sets are similar to the displacement sets in static analysis:

u_a	Structural analysis set
u_k	Aerodynamic box and body degrees of freedom
u_x	Aerodynamic “extra” points used to describe aerodynamic control surface deflections and overall rigid body motions, for example, angle of attack or roll acceleration

Finally, consider the j-set of aerodynamic control points. The j-set is not a user set; it is a notational set to identify aerodynamic matrices used in the solution processing. Physically, these are points on the structure where the downwash vectors are computed. As with the k-set, the location of these points is a function of the aerodynamic method employed:

- For Doublet-Lattice boxes, the control point is at the 75% chordwise station and spanwise center of the box
- For ZONA51 boxes, the control point is at the 95% chordwise station and the spanwise center of the box
- For Doublet-Lattice interference and slender body elements, the control point is along the axis of the element and at 50% of its length
- For all other theories, the aerodynamic control points are at the same physical location as the aerodynamic grid points discussed above

Internal Aerodynamic Theories

MSC Nastran has implemented seven internal aerodynamic theories:

1. Doublet-Lattice subsonic lifting surface theory (DLM)
2. ZONA51 supersonic lifting surface theory
3. Constant Pressure Method for supersonic lifting surface theory
4. Subsonic wing-body interference theory (DLM with slender bodies)
5. Mach Box method
6. Strip Theory
7. Piston Theory

The last three methods in the above list are now rarely used, but are described here for completeness. Each of these methods is described in this section, but they all share a common matrix structure.

Three matrix equations summarize the relationships required to define a set of aerodynamic influence coefficients [see Rodden and Revell (1962)[Reference 54]]. These are the basic relationships between the lifting pressure and the dimensionless vertical or normal velocity induced by the inclination of the surface to the airstream; that is, the downwash (or normalwash),

$$\{w_j\} = [A_{jj}]\{f_j/\bar{q}\} \tag{2-1}$$

the substantial differentiation matrix of the deflections to obtain downwash,

$$\{w_j\} = [D^1_{jk} + ikD^2_{jk}]\{u_k\} + \left\{w^g_j\right\} \tag{2-2}$$

and the integration of the pressure to obtain forces and moments,

$$\{P_k\} = [S_{kj}]\{f_j\} \tag{2-3}$$

where:

w_j	=	downwash
w^g_j	=	static aerodynamic downwash; it includes, primarily, the static incidence distribution that may arise from an initial angle of attack, camber, or twist
f_j	=	pressure on lifting element j
$\bar{q}$	=	flight dynamic pressure
k	=	reduced frequency, $k = \omega b/V$ where ω is the angular frequency, b is a reference semichord, and V is the free-stream velocity
$A_{jj}(m, k)$	=	aerodynamic influence coefficient matrix, a function of Mach number (m), and reduced frequency (k)
u_k, P_k	=	displacements and forces at aerodynamic grid points
D^1_{jk}, D^2_{jk}	=	real and imaginary parts of substantial differentiation matrix, respectively (dimensionless)
S_{kj}	=	integration matrix

The Aerodynamic Influence Coefficient Matrix

The three matrices of (2-1), (2-2), and (2-3) can be combined to give an aerodynamic influence coefficient matrix:

$$[Q_{kk}] = [S_{kj}][A_{jj}]^{-1}[D^1_{jk} + ikD^2_{jk}] \tag{2-4}$$

All aerodynamic methods compute the S, D^1, and D^2 matrices at user-supplied Mach numbers and reduced frequencies. The Doublet-Lattice and ZONA51 theories compute the A matrix. Then, matrix decomposition and forward and backward substitution are used in the computation of the Q matrix. The remaining methods compute A^{-1} directly and use matrix multiplications to form Q.

Doublet-Lattice Subsonic Lifting Surface Theory

The Doublet-Lattice method (DLM) can be used for interfering lifting surfaces in subsonic flow. The theory is presented by Albano and Rodden (1969) [Reference 1], Giesing, Kalman, and Rodden (1971) [Reference 18], and Rodden, Giesing, and Kalman (1972) [Reference 49] and is not reproduced here. The following general remarks summarize the essential features of the method.

The theoretical basis of the DLM is linearized aerodynamic potential theory. The undisturbed flow is uniform and is either steady or varying (gusting) harmonically. All lifting surfaces are assumed to lie nearly parallel to the flow. The DLM is an extension of the steady Vortex-Lattice method to unsteady flow.

Each of the interfering surfaces (or panels) is divided into small trapezoidal lifting elements ("boxes") such that the boxes are arranged in strips parallel to the free stream with surface edges, fold lines, and hinge lines lying on box boundaries. The unknown lifting pressures are assumed to be concentrated uniformly across the one-quarter chord line of each box. There is one control point per box, centered spanwise on the three-quarter chord line of the box, and the surface normalwash boundary condition is satisfied at each of these points.

The code for computing the aerodynamic influence coefficients A_{jj} was taken from Giesing, Kalman, and Rodden (1972b) [Reference 20]. Any number of arbitrarily shaped interfering surfaces can be analyzed, provided that each is idealized as one or more trapezoidal planes. Aerodynamic symmetry options are available for motions which are symmetric or antisymmetric with respect to one or two orthogonal planes. The user may supply one-half (or one-fourth) of the model and impose the appropriate structural boundary conditions. The full aircraft can also be modeled when the aircraft or its prescribed maneuvers lack symmetry.

ZONA51 Supersonic Lifting Surface Theory

ZONA51 is a supersonic lifting surface theory that accounts for the interference among multiple lifting surfaces. It is an optional feature in MSC Nastran (available as the Aero II option). It is similar to the Doublet-Lattice method (DLM) in that both are acceleration potential methods that need not account for flow characteristics in any wake. An outline of the development of the acceleration-potential approach for ZONA51 is presented by Liu, James, Chen, and Pototsky (1991) [Reference 33], and its outgrowth from the harmonic gradient method (HGM) of Chen and Liu (1985) [Reference 11]is described. ZONA51 is a linearized aerodynamic small disturbance theory that assumes all interfering lifting surfaces lie nearly parallel to the flow, which is uniform and either steady or gusting harmonically. As in the DLM, the linearized supersonic theory does not account for any thickness effects of the lifting surfaces.

Also, as in the DLM, each of the interfering surfaces (or panels) is divided into small trapezoidal lifting elements (boxes) such that the boxes are arranged in strips parallel to the free stream with surface edges, fold lines, and hinge lines lying on box boundaries. The unknown lifting pressures are assumed to be uniform on each box. There is one control point per box, centered spanwise on the 95 percent chord line of the box, and the surface normalwash boundary condition is satisfied at each of these points.

The code for computing the aerodynamic influence coefficients, A_{jj}, was integrated into MSC Nastran by Zona Technology, Inc., taking full advantage of the extensive similarities with the DLM. Any number of arbitrarily shaped interfering surfaces can be analyzed, provided that each is idealized as one or more trapezoidal planes. Aerodynamic symmetry options are available for motions that are symmetric or antisymmetric with respect to the vehicle centerline. Unlike the DLM, symmetry about the xy-plane is not supported. The user may supply one half of the vehicle model and impose the appropriate structural boundary conditions.

CPM (Constant Pressure Method) for Supersonic Lifting Surface Theory

MSC's acquisition of UAI brought with it the availability of another supersonic aerodynamic method entitled CPM (Constant Pressure Method). This method is available as an alternative to ZONA51 in that it provides the same basic functionality and uses the same user interface as the ZONA51 code. It supports multiple interfering lifting surfaces in the presence of an airflow that is supersonic (a guideline is Mach numbers ranging from $1.1<M<3.0$). Steady and unsteady loads are supported. CPM is provided in the Aero I option of MSC Nastran so that it does not require the Aero II option that enables use of the ZONA51 code. Tests performed on the input files used at MSC to perform regression testing have demonstrated that the two methods provide comparable results. It should be cautioned that this testing is limited and users are advised to make their own assessment as to the quality of the CPM code before adopting it.

The CPM method is discussed in detail in Bibliography 25.

Subsonic Wing-Body Interference Theory

The method of images, along with Slender Body Theory, was added to the Doublet-Lattice method (DLM) in Giesing, Kalman, and Rodden (1972a [Reference 19], 1972b [Reference 20], and 1972c [Reference 21]). The DLM is used to represent the configuration of interfering lifting surfaces, while Slender Body Theory is used to represent the lifting characteristics of each body (that is, fuselage, nacelle, or external store). The primary wing-body interference is approximated by a system of images of the DLM trailing vortices and doublets within a cylindrical interference body that circumscribes each slender body. The secondary wing-body interference that results from the DLM bound vortices and doublets is accounted for by a line of doublets located on the longitudinal axis of each slender body. The boundary conditions of no flow through the lifting surfaces or through the body (on the average about the periphery) lead to the equations for the lifting pressures on the surfaces and for the longitudinal (and/or lateral) loading on the bodies in terms of the normalwashes on the wing-body combination.

The code for computing the aerodynamic matrices was adapted for MSC Nastran from Giesing, Kalman, and Rodden (1972b) [Reference 20]. The adaptation required a matrix formulation of all of the body interference and body loading calculations. These equations are written using the symbols adopted for MSC Nastran and showing the equivalences to names used in the documentation of Giesing, Kalman, and Rodden (1972b) [Reference 20].

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The program of Giesing, Kalman, and Rodden (1972b) [Reference 20] finds the forces on the lifting boxes and bodies of an idealized airplane in terms of the motions of these elements. The lifting surfaces are divided into boxes. The bodies are divided into elements. There are two types of body elements: slender elements, which are used to simulate a body's own motion, and interference elements, which are used to simulate the interaction with other bodies and boxes. The body elements may have z (vertical), y (lateral), or both degrees of freedom.

The basic method is the superposition of singularities and their images. There are two basic singularity types: "forces" and modified acceleration potential "doublets." Each "force" singularity is equivalent to a line of doublets in the wake. As discussed, the wing boxes use the "force" type of singularity concentrated along the box quarter chord. The interference elements use the "doublet" type of singularity. The slender body elements use both types. Downwashes are related to the singularities by

$$\begin{Bmatrix} w_w \\ O \\ w_s \end{Bmatrix} = \begin{bmatrix} A_{ww} & A_{wI} & A_{ws} \\ A_{Iw} & A_{II} & A_{Is} \\ O & O & A_{ss} \end{bmatrix} \begin{Bmatrix} f_w/\bar{q} \\ \mu_I \\ \mu_s \end{Bmatrix} \tag{2-5}$$

where:

w_w	=	wing box downwashes at the three-quarter chord
w_s	=	downwashes for slender body elements
f_w	=	pressures concentrated along wing box quarter chords
μ_I	=	acceleration potential interference doublets
μ_s	=	acceleration potential slender element doublets (for flow fields only)
$\left[\begin{array}{c\|c} A_{ww} & A_{wI} \\ \hline A_{Iw} & A_{II} \end{array}\right]$	=	$[DT]$ in Giesing, Kalman, and Rodden (1972b, §5.3.1) [Reference 20]

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$$\begin{bmatrix} A_{ws} \\ \hline A_{Is} \end{bmatrix} = \begin{bmatrix} DZ \\ \hline DY \end{bmatrix}$$ in Giesing, Kalman, and Rodden (1972b, §5.3.1) [Reference 20]

$$A_{ss} = D2D^{-1}$$, which is a diagonal matrix discussed below where

$$D2D = \begin{cases} 2\pi a_0^2(1 + AR) \text{ for vertical motion} \\ 2\pi a_0^2 AR(1 + AR) \text{ for lateral motion} \end{cases}$$

where AR = body cross section height-to-width ratio

(2-6) relates the forces to the singularities:

$$\begin{Bmatrix} P_w \\ P_s \end{Bmatrix} = -\left[\begin{array}{c|c|c} S_{ww} & 0 & 0 \\ \hline S_{sw} & S_{sI} & S_{ss} \end{array}\right] \begin{bmatrix} f_w \\ \hline \mu_{I\bar{q}} \\ C_{s\bar{q}} \end{bmatrix} \tag{2-6}$$

where:

P_w	=	wing box force
P_s	=	body element force
C_s	=	slender element forces per unit length divided by dynamic pressure
$[S_{ww}]$	=	box areas (a diagonal matrix)
$\begin{bmatrix} S_{sw} & S_{sI} & S_{ss} \end{bmatrix}$	=	$[BFS]$ in Giesing, Kalman, and Rodden (1972b, §5.8.1 [Reference 20]), but rearranged in the order of the rows
S_{ss}	=	Δx = body element length

(2-5) and (2-6) use Method 1 of Giesing, Kalman, and Rodden (1972b) [Reference 20]. All of the above matrices have been modified to include the images of the sources caused by the symmetry plane.

In the slender body part of the program developed by Giesing, Kalman, and Rodden (1972b) [Reference 20], there is no matrix that relates the slender element forces, C_s, to the slender element doublets, μ_s. MSC was required to derive this matrix. This relationship between the forces and doublets involves only elements of the same body with the same orientation. The differential equation relating these distributions is

$$C_s(x) = \left(\frac{d}{dx} + i\frac{\omega}{U}\right)\mu_s(x) \tag{2-7}$$

where:

$C_s(x)$	=	lift per unit length/dynamic pressure (which has units of length)
$\mu_s(x)$	=	velocity potential doublet strength per unit length/free stream velocity (which has units of length^2)
x	=	streamwise coordinate
ω/U	=	unit reduced frequency (which has units of length^{-1})

The elements of the vector $\{C_s\}$ are $C(x_{center})\Delta x$, which are the total forces on the elements divided by the dynamic pressure. The elements of $\{\mu_s\}$ are $\mu(x_{center})$. The values of $\{C_s\}$ [called $\Delta C_p \Delta A$ by Giesing, Kalman, and Rodden (1972b) [Reference 20]] are evaluated from an equation that is equivalent to

$$C_s = \Delta x\left[\left(\frac{d}{dx} + i\frac{\omega}{U}\right)\mu_s(x)\right]_{x = x_{center}} \tag{2-8}$$

and

$$\mu_s(x) = (SB)w_s(x) \tag{2-9}$$

where:

(SB)	=	$\begin{cases} 2\pi a_0^2(1 + AR) \text{ for vertical motion} \\ 2\pi a_0^2 AR(1 + AR) \text{ for lateral motion} \end{cases}$
w_s	=	downwash (dimensionless)
$a_0(x)$	=	half width (dimensional radius)
AR	=	height/width ratio of body

The method used by Giesing, Kalman, and Rodden (1972b) [Reference 20] leads to a matrix, $[G]$, which relates the vector of $\{C_s\}$ to μ_s

$$\{C_s\} = [G]\{\mu_s\} \tag{2-10}$$

The derivation of $[G]$ assumes that $\mu_s / a_o^2(x)$, which is proportional to w_s, is a function of x. Thus, $\mu_s(x) = a_o^2(x)[\mu_s(x)/a_o^2(x)]$. Using (2-7),

$$C_s(x) = \left(\frac{\mu_s}{a_o^2}\right)\frac{d}{dx}(a_o^2) + (a_o^2)\left(\frac{d}{dx} + i\frac{\omega}{U}\right)\left(\frac{\mu_s}{a_o^2}\right) \tag{2-11}$$

$$= \left(\frac{2}{a_o}\frac{da_o}{dx} + i\frac{\omega}{U}\right)\mu_s + (a_o^2)\frac{d}{dx}\left(\frac{\mu_s}{a_o^2}\right)$$

The numerical derivatives required for the last term in (2-11) are evaluated by the following rules:

One point per body:	derivative = 0
Two or more points per body:	$\text{derivative} = \begin{cases} 2 \text{ point rule at end points} \\ 3 \text{ point rule at interior points} \end{cases}$

The two point rule comes from a linear fit and the three point rule from a quadratic fit. Examples are:

$$\left(\frac{dy}{dx}\right)_1 = \frac{y_2 - y_1}{x_2 - x_1} \qquad \text{(2-point)} \tag{2-12}$$

$$\left(\frac{dy}{dx}\right)_2 = \frac{y_2 - y_1}{x_2 - x_1} + \frac{y_3 - y_2}{x_3 - x_2} - \frac{y_3 - y_1}{x_3 - x_1} \qquad \text{(3-point)} \tag{2-13}$$

Using this, the elements of $[G]$ for one body are given by

$$G_{ij} = \delta_{ij}\left(\frac{2}{a_o}\frac{da_o}{dx} + i\frac{2k}{\bar{c}}\right) + g_{ij} \tag{2-14}$$

$$\delta_{ij} = \begin{cases} 1, & i = j \\ 0, & i \neq j \end{cases}$$

where:

$\bar{c}$ is the reference chord for the reduced frequency k, and g_{ij} is tridiagonal:

$$g_{ij} = \frac{(a_o^2)_i}{(a_o^2)_j} \times \begin{cases} \dfrac{1}{X_{i+1} - X_{i-1}} - \dfrac{1}{X_i - X_{i-1}} & \text{for } j = i\text{ -1} \\ \dfrac{1}{X_i - X_{i-1}} - \dfrac{1}{X_{i+1} - X_i} & \text{for } j = i \\ \dfrac{1}{X_{i+1} - X_i} - \dfrac{1}{X_{i+1} - X_i} & \text{for } j = i+1 \\ 0 & \text{otherwise} \end{cases} \tag{2-15}$$

For the first element $(i = 1)$, the terms involving x_{x-1} are deleted; for the last point $(i = N)$, the terms involving x_{i+1} are deleted.

(2-10) is used to eliminate the slender element forces C_s from (2-6), giving

$$\begin{Bmatrix} f_w \\ f_s \end{Bmatrix} = \left[\begin{array}{c|c|c} S_{ww} & 0 & 0 \\ \hline S_{sw} & S_{sI} & S_{ss}G \end{array}\right] \begin{Bmatrix} C_w \\ \mu_I \\ \mu_s \end{Bmatrix} = [S_{kj}]\{P_j\} \tag{2-16}$$

(2-5) and (2-16) permit relating the forces to the downwashes. The relationship of deflections to downwashes is given by (2-2). As can be seen from (2-5), there is zero “downwash” for all interference body elements, therefore, the rows of D^1_{jk} and D^2_{jk} associated with interference body elements vanish. All other rows represent total derivatives for downwashes of boxes and slender body elements. The basic form of (2-1) through (2-3) is kept, even in the case of panels with interference and slender bodies.

Mach Box Method

The Mach Box method (MBM) is used to estimate generalized aerodynamic forces on an isolated planar wing that has up to two (adjacent) trailing edge control surfaces, a crank on the leading and trailing edges, and is oscillating in supersonic flow. The MBM is a modification of the square box method first proposed by Pines, Dugundji, and Neuringer (1955) [Reference 38], outlined by Zartarian and Hsu (1955) [Reference 66]and Zartarian (1956) [Reference 65], and programmed by Moore and Andrew (1965) [Reference 35]and by Donato and Huhn (1968) [Reference 13]. Donato and Huhn (1968) [Reference 13] also present extensive comparisons of MBM results with exact theories. The general features of the method are summarized in the following remarks.

The MBM is a numerical solution of the linearized three-dimensional oscillatory supersonic perturbation potential flow equation. The regions disturbed by the vibrating lifting surface are divided into a grid of rectangular lifting elements, called Mach boxes (that is, rectangles with diagonals that are parallel to the Mach lines). The regions that are divided into Mach boxes include the wing and its control surfaces, as well as regions adjacent to the lifting surface that are within the envelope of aft Mach cones of the foremost points on the wing. Calculations are made of the influence of unit sources distributed uniformly over the area of each box on the velocity potential at the center of every box within its aft Mach cone. These are called velocity potential influence coefficients, and are functions of Mach number, reduced frequency, and relative locations of box centers. They are multiplied by the source strengths, defined by the normal velocity and perturbation angle of attack at the box center, and then summed to obtain the corresponding velocity potential at a downstream receiving point on the planform. When these velocity potential distributions are determined, they are multiplied by the complex conjugate of the source strength at the receiving point and summed over all such points to complete the calculation of the generalized aerodynamic force coefficients.

Note:	This is the variation on A^{-1} discussed in Internal Aerodynamic Theories; the matrix A_{jj} in (2-1) is never computed in MBM. Instead of relating pressures to downwashes, the MBM relates velocity potentials to downwashes and thereby circumvents the errors associated with numerical differentiation of the potentials to obtain pressures. Then the generalized aerodynamic forces are obtained directly from the potentials (by using an integration by parts) without the intermediate step of finding the pressures.

As with all potential theory methods, the accuracy of the MBM depends on the validity of supersonic linearized theory (which is generally assumed to be valid in the Mach number range from about 1.2 up to 3.0) and the number of Mach boxes with centers on the moving surface. At high Mach numbers the results approach those from first order Piston Theory.The supersonic Mach Box code used by MSC Nastran is based on subroutines in a modified version of the program of Donato and Huhn (1968) [Reference 13]; the modifications were made by L. V. Andrew, G. V. Owens, and J. W. Sleison to include the second control surface.

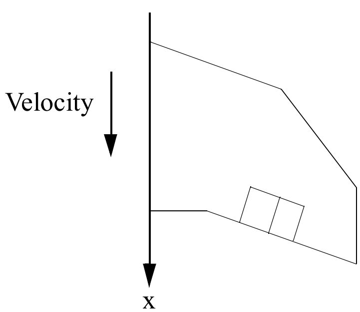

Figure 2-1 Platform Geometry for Mach Box Method

The general platform that can be analyzed is shown in Figure 2-1. The following options are available:

- Leading- and/or trailing-edge cranks
- None, one, or two adjacent trailing-edge control surfaces with swaybacked hinge lines
- Symmetric or antisymmetric motion

The free-stream velocity is parallel to the x-axis as shown in Figure 2-1 and a plane of symmetry is imposed at the inboard edge.

The Mach Box computer algorithm searches for the extreme streamwise point and the extreme spanwise point on the wing/control surface planform. They may be different points. It then reduces the user-supplied integer number of chordwise boxes to the closest floating point value (v 50) that places the side edge of a Mach box on the extreme spanwise point. If this array satisfies the criterion of less than a total number of 500 boxes (with v 50 spanwise) that contribute to the integral of generalized forces (that is, those partially on the main surface plus those cut by the trailing edge), and less than 200 boxes on each control surface that contribute to the integral, the grid is used to complete the analysis. If not, the number of chordwise boxes is sequentially reduced by one until both the edge criterion and the number criteria are satisfied, and then it proceeds to complete the analysis.

Strip Theory

The first solutions to the unsteady theoretical aerodynamic problem were obtained in two dimensions by Theodorsen (1935) [Reference 58] and by Küssner and Schwarz (1940) [Reference 31]. These solutions were utilized in flutter analyses by assuming that the loads at each spanwise station of a wing depended only on the motion of that station. An early method of flutter analysis, presented by Smilg and Wasserman (1942) [Reference 56], divided the wing into a number of strips, and the aerodynamic loads on each strip were calculated on the basis of the two-dimensional coefficients evaluated at the centerline of the strip. This "Strip Theory" was surprisingly accurate in many cases, although its successes were primarily in applications to unswept wings with high aspect ratios and may have been the result of compensating errors in the application of two-dimensional theory to three-dimensional flow. Because of its place in tradition, Strip Theory is included in MSC Nastran for use at the user's discretion.

The MSC Nastran code for computing A_{jj}^{-1} is based on Küssner and Schwarz (1940) [Reference 31] and is an extension of a program written by E. Albano at the Northrop Corporation. Although Küssner and Schwarz (1940) [Reference 31] include a trim tab, only the airfoil and an aerodynamically balanced control surface are considered in MSC Nastran. Both the airfoil and the control surface are assumed to be rigid in the chordwise direction, and the control surface hinge line is assumed to remain on the wing chord line (that is, no camber motions or hinge failures are considered).

The Theodorsen function for the unsteady circulatory loads is written as

$$C(k) = F(k) + iG(k) \tag{2-17}$$

where $k = \omega b/V$ is the local reduced frequency and b is the semichord of the strip. The user has the option of invoking $F(k)$ and $G(k)$ from their exact expressions in terms of Bessel functions, or from approximations of the form

$$F(k) = \sum_{n=0}^{N} \frac{b_n}{1 + (\beta_n/k)^2} \tag{2-18}$$

$$G(k) = \sum_{n=0}^{N} \frac{b_n(\beta_n/k)}{1+(\beta_n/k)^2} \tag{2-19}$$

in which $\beta_0 = 0$. The choice of values for the parameters b_n and β_n is left to the user. In this way, Strip Theory can be adjusted to account for compressibility or aspect ratio effects. Some values of b_n and β_n are tabulated on Bisplinghoff, Ashley, and Halfman (1955, pp. 350, 394) [Reference 8]. An approximate sweep correction is also incorporated; the correction is the factor $cos\Lambda$, where Λ is the one-quarter chord line sweep angle for the aerodynamic macro-element defined on the CAERO4 Bulk Data entry and is applied as a multiplier to all loads acting on the element.

Piston Theory

In the limit of high Mach number $(m^2 \gg 1)$ or high reduced frequency $(m^2k^2 \gg 1)$, the three-dimensional, pressure-downwash relationship on a lifting surface becomes a nonlinear uncoupled relationship at each point. The nonlinear point relationship can be linearized for small disturbances while retaining the nonlinear aspects of the initial steady-state condition. The result is known as third-order Piston Theory and was developed by Ashley and Zartarian (1956) [Reference 5].

A computer program to obtain A_{jj}^{-1} was written by Rodden, Farkas, Malcom, and Kliszewski (1962) [Reference 47]. The program uses much of the same logic as Strip Theory discussed previously. This computer code has been added directly to MSC Nastran with only minor adjustments for sign conventions and has the following general features: it is an extension of Ashley and Zartarian (1956) [Reference 5] to account for sweep and steady angle of attack and to decrease the lower supersonic Mach number limit so that agreement with Van Dyke (1952) [Reference 63] is obtained through the second-order terms. A rigid chord is assumed as well as a rigid trailing edge control surface hinged at its leading edge (that is, no aerodynamic balance is considered because that is not a design feature on supersonic vehicles). Experimental correlations have indicated the validity of Piston Theory in the range of Mach numbers from about 2.5 to 7.0.

Experimental Aerodynamic Corrections

The theoretical aerodynamic pressures are found from (2-1).

$$\{f_j\} = \bar{q}[A_{jj}]^{-1}\{w_j\} \tag{2-20}$$

Two experimental correction may be introduced into (2-3), so that the corrected force distribution becomes

$$\{P_k\} = [W_{kk}][S_{kj}]\{f_j\} + \bar{q}[S_{kj}]\left\{f_j^e/\bar{q}\right\} \tag{2-21}$$

where:

$[W_{kk}]$ = a matrix of empirical correction factors to adjust each theoretical aerodynamic box lift and moment to agree with experimental data for incidence changes; Giesing, Kalman, and Rodden (1976) [Reference 22] suggest one way of obtaining these factors.

$\left\{ f_j^e / \bar{q} \right\}$ = vector of experimental pressure coefficients at some reference incidence (for example, zero angle of attack) for each aerodynamic element.

Both corrections are appropriate in static aeroelastic analysis and provision for them has been made and is illustrated in a sample problem for static aeroelasticity in Static Aeroelastic Analysis Problems. However, the additive correction is not appropriate in the dynamic aeroelastic analyses since these are perturbation analyses. The multiplicative correction is illustrated in a sample problem for flutter analysis in Aeroelastic Analysis with MSC Nastran. Correction terms are input using DMI Bulk Data entries with names corresponding to those given in the sample problems.

External Aerodynamics

The discussion of the previous sub-chapter focussed on the aerodynamics that are available internally in MSC Nastran. These linear panel methods are ideal for aeroelastic applications in that they are relatively inexpensive to generate and the AICs (aerodynamic influence coefficients) provide a convenient way for incorporating aeroelastic effects. On the other hand, it is recognized that there are alternative aerodynamic methods that provide increased fidelity or are based on test results that are considered to provide an improved estimate of these effects. MSC Nastran provides several ways of incorporating this alternative data and this section begins the discussion on one of these. Apart from the internal aerodynamics, the user can specify a general mesh of aerodyanmic grid points and aerodynamic elements that connect these points. Aerodynamic forces or pressures can be applied to these grid points. Each grid point has its 123 components in the *k* set discussed above while the 456 components are in the *SA* set and therefore unavailable for imposing forces or for calculating displacements. It is not possible to submit this aerodynamic mesh along with the input for the internal aerodynamics of the previous sub-chapter but it is possilbe to combine these two types of meshes in a single analysis as described in Rigid/Flexible Meshes (to come).

Interconnection of the Structure with Aerodynamics

Introduction

Structural and aerodynamic grids are connected by interpolation. This allows the independent selection of grid points of the structure and aerodynamic elements of the lifting surfaces/bodies in a manner best suited to the particular theory. The structural model for a wing may involve a one-, two- or three-dimensional array of grid points. The aerodynamic theory may be any of those described in the previous two sub-Chapters. A general interpolation method is available that will interconnect the various combinations. Any aerodynamic panel or body can be subdivided into subregions for interpolation, using a separate function for each.

The interpolation method is called splining. The theory involves the mathematical analysis of beams and plates (see). Five methods are available:

- Linear splines, which allow torsional as well as translational and bending degrees of freedom
- Surface splines, which are solutions for uniform plates
- An explicit user-defined interpolation (The Constraint Spline)
- A rigid body spline that does transfers based only on geometry.
- A user-defined spline that is available via a client-server technique.

Multiple splines, including combinations of the five types, can be used in one model. For example, a model may use one spline for the horizontal tail and three splines for the wing (a surface spline for the inboard section, and a linear spline for the outboard wing section, and the explicit interpolation for the aileron). Separation into subregions allows discontinuous slopes (for example, at the wing-aileron hinge), separate functions (for wing and tail), and smaller regions. Smaller regions reduce the computing time and may increase the accuracy.

This section first details the numerous options that are available for creating the spline matrices and then concludes with the special topics of spline blending and spline relaxation.

The linear and surface splines have several options and different implementations:

- Various beam splines specify an axis about which the splining occurs and
  - are based on the equations of an infinite beam and can transfer to a regular arrays of aerodynamic boxes that are coplanar
  - are based on an infinite beam and can transfer to a regular or irregular array of aerodynamic boxes that do not have to be coplanar
  - are based on a radial interpolation method and can transfer to a regular or irregular array of aerodynamic boxes that do not have to be coplanar
  - are based on a 6DOF finite beam and can transfer up to 6 dof from the structure to the aero mesh or another structural mesh

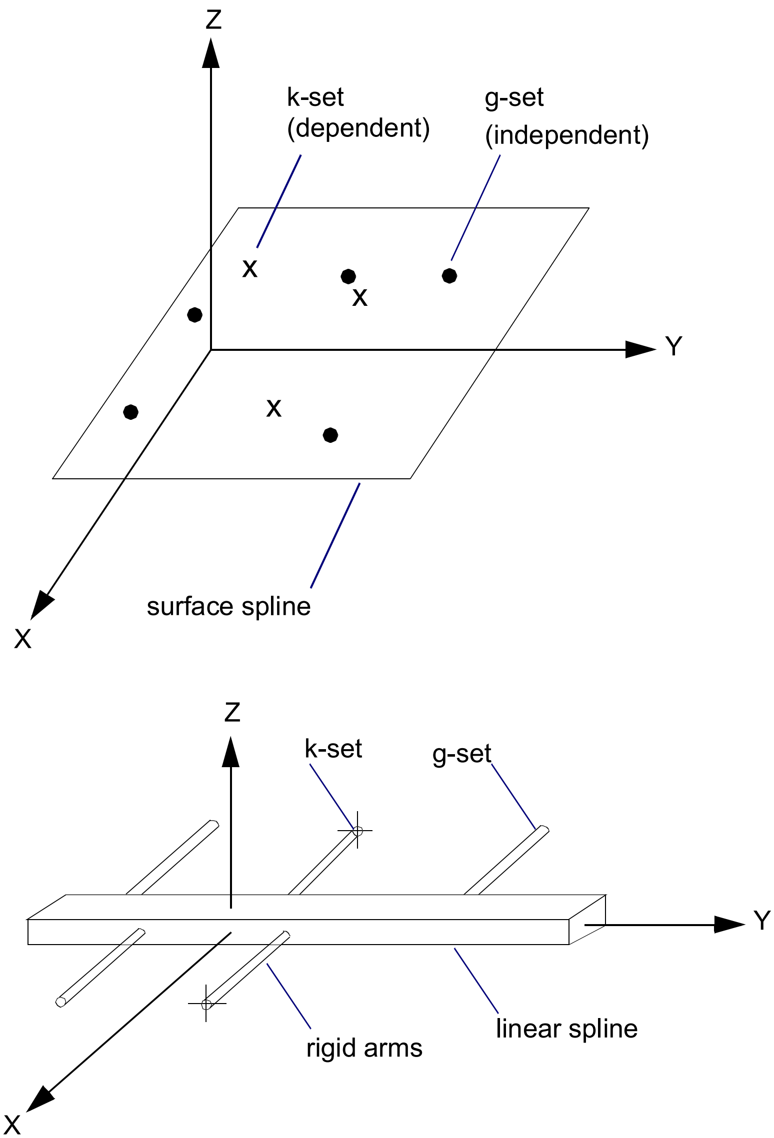

Figure 2-2 Splines and Their Coordinate Systems (note that the aerodynamic surface need not be flat for some of the options)

- Various surface splines
  - are based on the equations of an infinite flat plate and that can transfer to a regular or irregular array of boxes that are coplanar

- are based on the equations of a finite flat plate and that can transfer to a regular or irregular array of boxes that are coplanar
- are based on the equation of a thin plate and that can transfer to a regular or irregular array of boxes that need not be coplanar (if they are coplanar, the thin plate splines reverts to the infinite flat plate representation)
- are based on a radial interpolation method and can transfer to a regular or irregular array of aerodynamic boxes that do not have to be coplanar
- Are based on the equations of a finite plate with up to 6DOF's that can transfer to a general set of points that need not be coplanar.

The following options for aerodynamic splining are therefore discussed in this section.

A. Infinite Plate Spline

B. Infinite Beam Spline

C. The Finite Plate Spline

D. Thin Plate Spline

E. Radial Interpolation Spline

F. 6DOF Surface Spline

G. 6DOF Linear Spline

H. The Constraint Spline

I. The Rigid Body Spline

J. The User Defined Spline

The generality provided by these numerous options has been provided both to increase the fidelity of results when applied to the "classical" aerodynamic methods, such as Doublet Lattice, and to extend the scope of the methods when they are applied to more general aerodynamic meshes such as those used in CFD. This guide discusses this meshing in terms for transferring displacements and forces between a set of structural and aerodynamic points, although some of these same methods are capable of transferring between two structural meshes.

Splines provide an interpolation capability that couples the disjoint structural and aerodynamic models in order to enable aeroelastic analysis. The aeroelastic splines are used for two distinct purposes: as a force interpolator to compute a **structurally equivalent** force distribution on the structure given a force distribution on the aerodynamic mesh and as a displacement interpolator to compute a set of aerodynamic displacements given a set of structural displacements. The force interpolation is represented mathematically as:

$$\left[F_s\right] = \left[G_{sa}\right]\left[F_a\right] \tag{2-22}$$

and the displacement interpolation as:

$$\left[U_a\right] = \left[G_{as}\right]\left[U_s\right] \tag{2-23}$$

Where G is the spline matrix, F and U refer to forces and displacements, respectively and the s and a subscripts refer to structure and aerodynamics, respectively.

The two splines given in the above relationships are used when making the force and displacement interpolations. However, virtual work principals can be applied to relate the two splines as being the transform of one another:

$$[G_{sa}] = [G_{as}]^T \tag{2-24}$$

That is, the same set of aerodynamic and structural degrees of freedom are coupled for both interpolation functions. While this relationship is valid, this usage assumption is not necessary and can be limiting for static aeroelastic applications where the set of structural DOFs that is appropriate for load application may not be the same set that is appropriate to represent the important deflections for the aeroelastic correction. Therefore, each spline can be either General (same spline used for Force and Displacement), Displacement or Force.

As stated in (2-22) and (2-23), the two basic relationships that must be developed are the displacement transformation and the force transformation. In general, the structural displacements are the usual six global displacement degrees of freedom and the forces are the usual three forces and three moments. The aerodynamic degrees of freedom depend on the aerodynamic method, but must include displacements normal to a local surface and rotations about an axis lying in the osculatory plane since these are the degrees of freedom used in the internal aerodynamic methods. The corresponding aerodynamic forces are a normal force and a local pitching moment.

Each set of structural points and aerodynamic points may be related via a pair of unique spline transformations of the form of (2-22) and (2-23). The total transformation matrices for all the aerodynamic and structural DOFs are then assembled from the individual spline matrices. The structural points are taken as the independent degrees of freedom in the spline relationships, so the same structural point may appear in more than one spline relation. Each aerodynamic point may appear in only one unless the blending feature of external aerodynamics is used.

The force transformation must be computed such that the resultant structural loads are statically equivalent to the aerodynamic loads:

$$\sum_{i=1}^{3ns} [TBG]_i [F_s]_i = \sum_{j=1}^{3na} [TBA]_j [F_a]_j \tag{2-25}$$

where $[TBG]$ is the transformation from global to basic coordinates. For moments, the following condition must be satisfied:

$$\sum_{i=1}^{3ns} [r]_i \times [TBG]_i [F_s]_i = \sum_{j=1}^{3na} [r]_j \times [TBA]_j [F_a]_j \tag{2-26}$$

where the $[r]_i$, $[r]_j$ are, respectively, the vectors between the (arbitrary) moment center and the structural and aerodynamic mesh points in the basic coordinate system. These two requirements are imposed on the individual spline matrices on a component-by-component basis, thus ensuring that the relationship will hold for the assembled spline transformation.

Each of the spline methods yields a relationship:

$$\{U(x,y,z)\} = [R]\{a\} + [\bar{A}]\{P\} = [C][P] \tag{2-27}$$

where $[R]\{a\}$ are the weighted coefficients of the interpolant (usually determined by boundary conditions on the function, e.g., equilibrium) and $[\bar{A}]\{P\}$ are the coefficient matrix and the applied load respectively. The coefficient matrix is a function only of geometry and the form of the interpolant. The evaluation uses the structural geometry alone in (2-27) to evaluate the coefficients:

$$\{P_s\} = \left[C_{ss}\right]^{-1}\{U_s(x,y,z)\} \tag{2-28}$$

and then uses (2-27) again, with both geometries to evaluate the displacement function at the aerodynamic points given the solution of (2-28) (which are loads at the structural grids) for point displacements at the structural grids.

$$\{U_a(x,y,z)\} = [R_a]\{a\} + [\bar{A}_{as}]\{P_s\} \tag{2-29}$$

In other words, to create the spline transformation matrix, (2-27) is evaluated for point loads at the structural points to form basis vectors at the aerodynamic points that are the columns of the displacement transformation of (2-22).

It should be mentioned here that MSC Nastran supports the option of having a separate spline matrix for force and displacement transformation. The algorithms used are identical in the two cases but the set of points used in the splining could be different. The rationale for allowing separate force and displacement splines that a grid that is appropriate for predicting aerodynamic displacement may not be good for applying forces. For example, a grid point on a wing surface that is not attached to substructure may be needed to get a smooth pattern on the aerodynamic mesh but may load the structure inappropriately if it is included in the force transformation. The notations to describe these two splines are:

$[G^D_{kg}]$ - Transformation matrix to transform displacements from the structural grid to the aerodynamic grid.

$\left[G^P_{kg}\right]^T$ - Transformation matrix to transform forces from the aerodynamic grid to the structural grid.

Theory of Infinite Plate Splines (IPS)

A surface spline is a mathematical tool used to find a surface function, $w(x, y)$, for all points (x, y) when w is known for a discrete set of points, $w_i = w(x_i, y_i)$. The Infinite Plate Spline is a special surface spline that is tailored to legacy flat plate aerodynamics. The following derivation is given in some detail because a.) the write-up is available from earlier versions of this Guide and b). the remaining methods can be related to the IPS. The theory introduces an infinite plate and solves for its deflections, given its deflections at a discrete set of points; that is, it is the problem of a plate with multiple deflecting supports. The surface spline is a smooth continuous function that will become nearly linear in x and y at large distances from the points (x_i, y_i). This problem can be solved in closed form.

The deflection of the plate is synthesized as the sum of deflections due to a set of point loads on the infinite plate. The deflection due to a single concentrated load is the fundamental solution and has polar symmetry. If the load is taken at $x_i = y_i = 0$, and polar coordinates are used $(x = r\ cos\theta, y = r\ sin\theta)$, the governing differential equation is

$$D\nabla^4 w = D\frac{1}{r}\frac{d}{dr}\left\{r\frac{d}{dr}\left[\frac{1}{r}\frac{d}{dr}\left(r\frac{dw}{dr}\right)\right]\right\} = q \tag{2-30}$$

The distributed load q vanishes except near $r = 0$. The general solution to the homogeneous form of (2-30) is

$$w = C_0 + C_1 r^2 + C_2 ln r + C_3 r^2 ln r \tag{2-31}$$

Set $C2 = 0$ to keep the solution finite as $r \to 0$. Then multiply (2-30) by $2\pi r$ and integrate from $r = 0$ to $r = \varepsilon$ (a small number) to obtain the concentrated force P,

$$P = \lim_{r \to 0}\int_0^{\varepsilon} 2\pi rq\ dr = \lim_{r \to 0} 2\pi r D\frac{d}{dr}\left[\frac{1}{r}\frac{d}{dr}\left(r\frac{dw}{dr}\right)\right] \tag{2-32}$$

Combining (2-31) and (2-32) leads to $C_3 = P/(8\pi D)$. The fundamental solution may therefore be written

$$w = A + Br^2 + (P/16\pi D)r^2 ln r^2 \tag{2-33}$$

since $ln r = \frac{1}{2} ln r^2$

The fundamental solutions are superimposed to solve the entire plate problem with a solution of the form

$$w(x, y) = \sum[A_i + B_i r_i^2 + (p/16\pi D)r_i^2 ln r_i^2] \tag{2-34}$$

where: $r_i^2 = (x - x_i)^2 + (y - y_i)^2$.

The remaining requirement is the satisfaction of the boundary condition at infinity: Radial lines emanating from loaded points (which all may be regarded as at the origin relative to infinity) appear to be straight lines. To do this, (2-34) is expanded in a series, assuming a large argument $(x^2 + y^2)$, and delete all terms of order $(x^2 + y^2) ln(x^2 + y^2)$, $(x^2 + y^2)$, $x\ ln(x^2 + y^2)$, and $y\ ln(x^2 + y^2)$, leaving terms of order x, y, $ln(x^2 + y^2)$, and 1. The details of the series expansion are given by Harder, MacNeal, and Rodden (1971) [Reference 25]. The deletion of the higher-order terms is accomplished by requiring

$$\sum B_i = 0 \tag{2-35}$$

$$\sum P_i = 0 \tag{2-36}$$

$$\sum x_i P_i = 0 \tag{2-37}$$

$$\sum y_i P_i = 0 \tag{2-38}$$

(2-35) through (2-38) result in linear deflections at infinity; (2-36) through (2-38) are also recognized as the equations of equilibrium. From (2-35) it is seen that

$$\sum (A_i + B_i r_i^2) = a_0 + a_1 x + a_2 y \tag{2-39}$$

A solution to the general spline problem, formed by superimposing solutions of (2-30), is given by

$$w(x, y) = a_0 + a_1 x + a_2 y + \sum_{i=1}^{N} K_i(x, y) P_i \tag{2-40}$$

where:

$$K_i(x, y) = (1/(16\pi D)) r_i^2 \, ln \, r_i^2$$

$$r_i^2 = (x - x_i)^2 + (y - y_i)^2$$

P_i = concentrated load at (x_i, y_i)

The $N + 3$ unknowns $(a_0, a_1, a_2, P_i; i = 1, N)$ are determined from the $N + 3$ equations

$$\sum P_i = \sum x_i P_i = \sum y_i P_i = 0 \tag{2-41}$$

and

$$w_j = a_0 + a_1 x_j + a_2 y_2 + \sum_{i=1}^{N} K_{ij} P_i \qquad (j = 1, N) \tag{2-42}$$

where $K_{ij} = K_i(x_j, y_j)$. Note that $K_{ij} = K_{ji}$, and $K_{ij} = 0$ when $i = j$. The above derivation is also summarized by Harder and Desmarais (1972a) [Reference 19] and an application is shown. It is discussed further by Rodden, McGrew, and Kalman (1972) [Reference 52] and by Harder and Desmarais (1972b) [Reference 24]. (2-40) can be rewritten in the matrix form:

$$w(x,y) = 1, x, y, K_1(x,y), K_2(x,y), \ldots, K_N(x,y)\begin{Bmatrix} a_0 \\ a_1 \\ a_2 \\ P_1 \\ P_2 \\ \vdots \\ P_N \end{Bmatrix} \tag{2-43}$$

Combining (2-40) and (2-41) into the matrix form

$$\begin{Bmatrix} 0 \\ 0 \\ 0 \\ \hline w_1 \\ w_2 \\ \vdots \\ w_N \end{Bmatrix} = \left[\begin{array}{ccc|cccc} 0 & 0 & 0 & 1 & \ldots & 1 \\ 0 & 0 & 0 & x_1 & \ldots & x_N \\ 0 & 0 & 0 & y_1 & \ldots & y_N \\ \hline 1 & x_1 & y_1 & 0 & \ldots & K_{1N} \\ 1 & x_2 & y_2 & K_{21} & \ldots & K_{2N} \\ \vdots & \vdots & \vdots & \vdots & \ldots & \vdots \\ 1 & x_N & y_N & K_{N1} & \ldots & 0 \end{array}\right]\begin{Bmatrix} a_0 \\ a_1 \\ a_2 \\ \hline P_1 \\ P_2 \\ \vdots \\ P_N \end{Bmatrix} = [C][P] \tag{2-44}$$

permits solution for the vector of a_i and P_i. The interpolation to any point in the (x, y) plane is then achieved by evaluating $w(x, y)$ from (2-43) at the desired points. This gives an overall equation of the form

$$\{w\}_a = \begin{bmatrix} 1 & x_{1a} & y_{1a} & K_{1a,1} & K_{1a,2} & \ldots & K_{1a,n} \\ 1 & x_{2a} & y_{2a} & K_{2a,1} & K_{2a,2} & \ldots & K_{2a,n} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \ldots & \vdots \\ 1 & x_{na} & x_{na} & K_{na,1} & K_{na,2} & \ldots & K_{na,n} \end{bmatrix}[C]^{-1}\begin{Bmatrix} 0 \\ 0 \\ 0 \\ w_1 \\ w_2 \\ \vdots \\ w_N \end{Bmatrix} \tag{2-45}$$

Main Index

Slopes of the aerodynamic panels, which are the negative of the slopes of the displacements, are also required. These are found by analytically differentiating (2-45) with respect to x,

$$\{\alpha\}_a = -\left\{\frac{\partial w}{\partial x}\right\}_a = -\begin{bmatrix} 0 & 1 & 0 & DK_{1a,1} & \cdots & DK_{1a,n} \\ \vdots & \vdots & \vdots & \vdots & \cdots & \vdots \\ 0 & 1 & 0 & DK_{na,1} & \cdots & DK_{na,n} \end{bmatrix} [C]^{-1} \begin{Bmatrix} 0 \\ 0 \\ 0 \\ w_1 \\ \vdots \\ w_N \end{Bmatrix} \tag{2-46}$$

where:

$$DK_{ij} = \frac{\partial K_i(x_j, y_j)}{\partial x} = \left(\frac{x - x_i}{8\pi D}\right)(1 + ln r_i^2) \tag{2-47}$$

Theory of Infinite Beam Splines

A linear spline is a "beam" function, $w(x)$, which passes through the known deflections, $w_i = w(x_i)$ with twists $\phi_i = \phi(x_i)$. Bending deflections are easily solved by the three-moment method, which is appropriate for simple beams. However, an extension of the method is required for splines with torsion, rigid arms, and attachment springs. The following derivations outlined are based on analogy with the surface spline derivation.

Bending Bars

Equation for deflection

$$EI\frac{d^4w}{dx^4} = q - \frac{dM}{dx} \tag{2-48}$$

where q is a distributed transverse load and M is a distributed moment.

A symmetric fundamental solution for $x \neq 0$ is used for lateral loads $q = P\delta(x)$, where $\delta(x)$ is the Dirac δ-function, and an antisymmetric fundamental solution is used for moments. The solution for the general case is found by superimposing the fundamental solutions,

$$w(x) = a_0 + a_1 x + \sum_{i=1}^{N}\left(-\frac{M_i(x-x_i)|x-x_i|}{4EI} + \frac{P_i|x-x_i|^3}{12EI}\right) \tag{2-49}$$

$$\theta(x) = \frac{dw}{dx} = a_1 + \sum_{i=1}^{N}\left(-\frac{M_i|x-x_i|}{2EI} + \frac{P_i(x-x_i)|x-x_i|}{4EI}\right) \tag{2-50}$$

These are written in matrix notation as

$$\begin{Bmatrix} w(x) \\ \theta(x) \end{Bmatrix} = \begin{bmatrix} 1 & x & \frac{|x-x_1|^3}{12EI} & \dots & -\frac{(x-x_1)|x-x_1|}{4EI} & \dots \\ 0 & 1 & \frac{(x-x_1)|x-x_1|}{4EI} & \dots & -\frac{|x-x_1|}{2EI} & \dots \end{bmatrix} \begin{Bmatrix} a_0 \\ a_1 \\ P_1 \\ \vdots \\ P_N \\ M_1 \\ \vdots \\ M_N \end{Bmatrix} \tag{2-51}$$

To satisfy the boundary condition at infinity, $w(x)$ must approach a linear function. This requires

$$\sum P_i = 0 \tag{2-52}$$

$$\sum (x_i P_i + M_i) = 0 \tag{2-53}$$

These are recognized as the equations of equilibrium. The unknowns a_i, P_i, and M_i are found from

$$\begin{Bmatrix} 0 \\ 0 \\ \dots \\ W_1 \\ \vdots \\ W_N \\ \dots \\ \theta_1 \\ \vdots \\ \theta_N \end{Bmatrix} = \begin{bmatrix} 0 & R_1^T & R_2^T \\ R_1 & A_{11} & A_{21} \\ R_2 & A_{21} & A_{22} \end{bmatrix} \begin{Bmatrix} a_0 \\ a_1 \\ \dots \\ P_1 \\ \vdots \\ P_N \\ \dots \\ M_1 \\ \vdots \\ M_N \end{Bmatrix} \tag{2-54}$$

where it has been assumed that $x_1 < x_2 \dots < x_N$, and

$$R_1^T = \begin{bmatrix} 1 & 1 & \dots & 1 \\ x_1 & x_2 & \dots & x_N \end{bmatrix}$$

$$R_2^T = \begin{bmatrix} 0 & 0 & \dots & 0 \\ 1 & 1 & \dots & 1 \end{bmatrix}$$

$$A_{11} = \begin{bmatrix} 0 & \dfrac{(x_2 - x_1)^3}{12EI} & \dots & \dfrac{(x_N - x_1)^3}{12EI} \\ \dfrac{(x_2 - x_1)^3}{12EI} & 0 & \dots & \dfrac{(x_N - x_1)^3}{12EI} \\ \vdots & \vdots & \dots & \vdots \\ \dfrac{(x_N - x_1)^3}{12EI} & \dfrac{(x_N - x_1)^3}{12EI} & \dots & 0 \end{bmatrix}$$

$$A_{21} = \begin{bmatrix} 0 & -\frac{(x_2 - x_1)^2}{4EI} & \dots & -\frac{(x_N - x_1)^2}{4EI} \\ \frac{(x_2 - x_1)^2}{4EI} & 0 & \dots & -\frac{(x_N - x_2)^2}{4EI} \\ \vdots & \vdots & \dots & \vdots \\ \frac{(x_N - x_1)^2}{4EI} & \frac{(x_N - x_2)^2}{4EI} & \dots & 0 \end{bmatrix}$$

$$A_{22} = \begin{bmatrix} 0 & -\frac{(x_2 - x_1)}{2EI} & \dots & -\frac{(x_N - x_1)}{2EI} \\ -\frac{(x_2 - x_1)}{2EI} & 0 & \dots & -\frac{(x_N - x_2)}{2EI} \\ \vdots & \vdots & \dots & \vdots \\ -\frac{(x_N - x_1)}{2EI} & -\frac{(x_N - x_2)}{2EI} & \dots & 0 \end{bmatrix}$$

Torsion Bars

Equation for twist:

$$GJ\left(\frac{d^2\phi}{dx^2}\right) = -t \tag{2-55}$$

where t is a distributed torque. The solution is

$$\phi(x) = \left[1 - \frac{|x_1 - x|}{2GJ} - \frac{|x_2 - x|}{2GJ} \dots - \frac{|x_N - x|}{2GJ}\right] \begin{Bmatrix} a_0 \\ T_1 \\ T_2 \\ \\ T_N \end{Bmatrix} \tag{2-56}$$

To satisfy the condition that ϕ = constant for large x requires the equilibrium condition

$$\sum T_i = 0 \tag{2-57}$$

Then the unknowns a_0 and T_i are found by solving

$$\begin{Bmatrix} 0 \\ \dots \\ \phi_1 \\ \phi_2 \\ \vdots \\ \phi_N \end{Bmatrix} = \begin{bmatrix} 0 & 1 & 1 & \dots & 1 \\ 1 & 0 & -\frac{|x_2 - x_1|}{2GJ} & \dots & -\frac{|x_N - x_1|}{2GJ} \\ 1 & -\frac{|x_2 - x_1|}{2GJ} & 0 & \dots & -\frac{|x_N - x_2|}{2GJ} \\ \vdots & \vdots & \vdots & \dots & \\ 1 & -\frac{|x_N - x_1|}{2GJ} & -\frac{|x_N - x_2|}{2GJ} & \dots & 0 \end{bmatrix} \begin{Bmatrix} a_0 \\ T_1 \\ T_2 \\ \vdots \\ T_N \end{Bmatrix} \tag{2-58}$$

Attachment of Splines with Elastic Springs

If a number of grid points are located closely, forcing the splines through each deflected point may cause some erratic behavior at a distance from the cluster. For this reason elastic spring connections to smooth the spline have been introduced. The change in the formulas for splines to accommodate flexible supports is straightforward. A derivation, valid for the several types of splines, follows. The spline definition is given by (2-44), (2-54), and (2-58) and can be written as

$$\{0\} = [R_i]^T\{P\} \tag{2-59}$$

$$\{u_k\} = [R_i]\{a\} + [A_{ij}]\{P\} \tag{2-60}$$

The structural deflection, u_g, will differ from the spline deflection by the deformation of the spring, resulting in forces

$$\{P\} = [K_s]\{u_g - u_k\} \tag{2-61}$$

where the diagonal matrix, K_s, has the spring constant, K, along the diagonal. These are nonzero (if K were equal to zero, then there would be no attachment and that grid point would be discarded) and thus the inverse of K_s is

$$[K_s]^{-1} = \begin{bmatrix} 1/K & \dots & 0 \\ \vdots & \dots & \vdots \\ 0 & \dots & 1/K \end{bmatrix} \tag{2-62}$$

Eliminating u_k between (2-60) and (2-61) and leads to

$$\{u_g\} = [R_i]\{a\} + ([A_{ij}] + [K_s]^{-1})\{P\} \tag{2-63}$$

Thus, all that is required to accommodate springs is to add the spring flexibilities to the diagonal of the spline influence coefficient matrix. This is also obvious from physical reasoning, since the spring and spline flexibilities are in series and can be added directly.

Rigid Arms on Linear Splines

The linear splines used for geometry interpolation have rigid arms (see). Mathematically, these rigid arms represent equations of constraint between the displacements and rotations at the spline and the attachment point of the aerodynamic element. Physically, these rigid arms correspond to the assumption of a structure with a rigid chord perpendicular to the linear spline (elastic axis). The equations of constraint for the rigid arms are used to transform the influence functions from the spline ends to influence functions at the attachment points. The complete transformed influence functions are summarized at the end of this section.

Summary of Matrices for Infinite Surface and Beam Spline Interpolation

- The A_{ij} matrix in (2-60) for surface splines is

$$A_{ij} = \begin{bmatrix} \dfrac{r_{ij}^2 ln r_{ij}^2}{16\pi D} + \dfrac{\delta_{ij}}{k_z} \\ \dfrac{(y_i - y_j)(1 + ln r_{ij}^2)}{8\pi D} \\ -\dfrac{(x_i - x_j)(1 + ln r_{ij}^2)}{8\pi D} \end{bmatrix}$$

where:

$$r_{ij}^2 = (x_i - x_j)^2 + (y_i - y_j)^2$$

$$\delta_{ij} = \begin{cases} 1 \text{ for } i = j \\ 0 \text{ for } i \neq j \end{cases}$$

and k_z is the translational stiffness of an attached spring.

- The R_i matrix in (2-60) for surface and linear splines is

$$[R_i] = \begin{bmatrix} 1 & y_i & -x_i \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

- The A_i matrix in (2-60) for linear splines is

$$[A_{ij}] = \left[\begin{array}{c|c|c} \frac{|y_i - y_j|^3}{12EI} - \frac{x_i x_j |y_i - y|}{2GJ} + \frac{\delta_{ij}}{k_z} & -\frac{|y_i - y_j|(y_i - y_j)}{4EI} & \frac{x_i |y_i - y_j|}{2GJ} \\ \hline \frac{|y_i - y_j|(y_i - y_j)}{4EI} & -\frac{|y_i - y_j|}{2EI} + \frac{\delta_{ij}}{k_\theta} & 0 \\ \hline \frac{x_j |x_i - x_j|}{2GJ} & 0 & -\frac{|y_i - y_j|}{2GJ} + \frac{\delta_{ij}}{k_\phi} \end{array}\right]$$

where k_θ and k_ϕ are rotational stiffness of the attached springs.

Thin Plate Spline

The thin plate spline (TPS) is a generalization of the IPS to three dimensions. The derivation is entirely analogous with the IPS with the addition of the third coordinate. The superimposed fundamental solutions remain

$$w(x, y, z) = \sum[A_i + B_i r_i^2 + (P_i / 16\pi D) r_i^2 \ln r_i^2] \tag{2-64}$$

but now $r_i^2 = (x - x_i)^2 + (y - y_i)^2 + (z - z_i)^2$. The boundary conditions at infinity now require the addition of the moment in the third axis:

$$\sum B_i = 0 \tag{2-65}$$

$$\sum P_i = 0 \tag{2-66}$$

$$\sum x_i P_i = 0 \tag{2-67}$$

$$\sum y_i P_i = 0 \tag{2-68}$$

$$\sum z_i P_i = 0 \tag{2-69}$$

A solution to the general spline problem, formed by superimposing solutions of (2-64), is given by

$$w(x, y, z) = a_0 + a_1 x + a_2 y + a_3 z + \sum_{i=1}^{N} K_i(x,y,z) P_i \tag{2-70}$$

$$K_i(x,y,z) = (1/16\pi D) r_i^{\,2} \ln r_i^{\,2}$$

$$r_i^{\,2} = (x - x_i)^2 + (y - y_i)^2 + (z - z_i)^2$$

and P_i is the concentrated load at (x_i, y_i, z_i)

The *N*+4 unknowns $(a_0, a_1, a_2, a_3, P_i; i = 1, N)$ are determined from the 4 equilibrium equations (2-66) through (2-69) and the N equations

$$w_j(x_j, y_j, z_j) = a_0 + a_1 x_j + a_2 y_j + a_3 z_j + \sum_{i=1}^{N} K_{i,j} P_i \,; j = 1, N \tag{2-71}$$

$$K_{i,j} = K_i(x_j, y_j, z_j) = (1/16\pi D) r_{i,j}^{\,2} \ln r_{i,j}^{\,2} \tag{2-72}$$

$$r_{i,j}^{\,2} = (x_j - x_i)^2 + (y_j - y_i)^2 + (z_j - z_i)^2 \tag{2-73}$$

The coefficient matrix can then be assembled that permits solution for the vector of a_i and P_i. The interpolation to any point (x,y,z) is then achieved by evaluating $w(x,y,z)$ from (2-70), at the desired points. This gives an overall equation relating the **M** dependent aerodynamic points to a displacement pattern at the **N** independent structural points:

$$\{w\}_a = \begin{bmatrix} 1 & x_1 & y_1 & z_1 & K_{1,1} & K_{1,2} & \dots & K_{1,N} \\ 1 & x_2 & y_2 & z_2 & K_{2,1} & K_{2,2} & \dots & K_{2,N} \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ 1 & x_M & y_M & z_M & K_{M,1} & K_{M,2} & \dots & K_{M,N} \end{bmatrix} [C]^{-1} \begin{Bmatrix} 0 \\ 0 \\ 0 \\ w_1 \\ w_2 \\ \dots \\ w\ N \end{Bmatrix} = [K][C]^{-1} \begin{Bmatrix} 0 \\ 0 \\ 0 \\ w_1 \\ w_2 \\ \dots \\ w\ N \end{Bmatrix} \tag{2-74}$$

In the derivation, we have not indicated the meaning of the scalar P_i (2-64), but we can now take them to be a set of forces in one coordinate direction. In that case, (2-74) provides an interpolation between forces in one direction and displacements in that direction with equilibrium preservation. We can apply that transform for each translational direction to build a three dimensional interpolant. With this observation, we now can assemble the local spline matrix that relates the aerodynamic degrees of freedom to the structural degrees of freedom for the DOF's that are participating in the particular application of the TPS:

$$\{u_a\}\big|_{tran} = \begin{Bmatrix} u_1 \\ \dots \\ u_M \\ v_1 \\ \dots \\ v_M \\ w_1 \\ \dots \\ w_M \end{Bmatrix}_a = [T^t{}_{ap}] \begin{bmatrix} [K][C^{-1}] & 0 & 0 \\ 0 & [K][C^{-1}] & 0 \\ 0 & 0 & [K][C^{-1}] \end{bmatrix} \begin{bmatrix} P_I & 0 & 0 \\ 0 & P_I & 0 \\ 0 & 0 & P_I \end{bmatrix} \tag{2-75}$$

$$[T_{ps}]\{u_g\} = \left[G^t{}_{as}\right]\{u_g\}$$

$$\{u_a\}\Big|_{rot} = \left\{\begin{matrix} \theta_{x_1} \\ \dots \\ \theta_{x_M} \\ \theta_{y_1} \\ \dots \\ \theta_{y_M} \\ \theta_{z_1} \\ \dots \\ \theta_{z_M} \end{matrix}\right\}_a = [T^r{}_{ap}]\begin{bmatrix} [\partial K]\left[C^{-1}\right] & 0 & 0 \\ 0 & [\partial K]\left[C^{-1}\right] & 0 \\ 0 & 0 & [\partial K]\left[C^{-1}\right] \end{bmatrix}\begin{bmatrix} P_I & 0 & 0 \\ 0 & P_I & 0 \\ 0 & 0 & P_I \end{bmatrix} \tag{2-76}$$

$$[T_{ps}]\{u_g\} = \left[G^r{}_{as}\right]\{u_g\}$$

$$\left[P_I\right] = \begin{bmatrix} 0 & 0 & \dots & 0 \\ 0 & 0 & \dots & 0 \\ 0 & 0 & \dots & 0 \\ 1 & 0 & \dots & 0 \\ 0 & 1 & \dots & 0 \\ \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & 1 \end{bmatrix}_{3+N \times N} \tag{2-77}$$

and $[T^t{}_{ap}]$,$[T^r{}_{ap}]$ are the three assembled 3x3 transformation matrices that relate the aerodynamic coordinate system to the spline coordinate system. Similarly, $[T_{ps}]$ is the assembled 3x3 transformation matrix that relates the structural displacements to the spline component directions. Just as in the 2-D case, the structural rotations are not involved in this spline formulation.

Most of the difference between this 3-D version and its 2-D counterpart is in the formation of the $[T^t{}_{ap}]$,$[T^r{}_{ap}]$, $[T_{ps}]$ matrices to account for separate treatment of each displacement component instead of a single planar interpolation surface.

Singularity Conditions: In the 2-D case, the spline interpolant is singular if the independent (structural) points are all collinear. In the 3-D case, the interpolant is singular if the independent points are all coplanar. If the TPS interpolant is found to be singular, the code automatically reverts to a 2-D interpolant with the spline plane defined by the plane of the coplanar structural grid points. In the case of a singular 2-D case, a fatal error is issued, since we do not attempt to revert to a beam spline.

Two Dimensional Finite Plate Spline

The finite plate spline (FPS) is a method that uses a mesh of elemental quadrilateral or triangular plates to compute the interpolation function. It is similar to the IPS and beam spline methods in that the interpolant is based on structural behavior, but is different in that the equations are a discretized approximation of a finite structural component. A finite plate approximation has the advantage of being able to more closely approximate the boundary conditions at the edge of the interpolation region: boundary conditions at infinity are replaced by an FE (finite element) approximation of the independent degrees of freedom extrapolated to the plate edges. This methodology has been shown (Appa, 1989) to limit the “potato chip” effect observed in extrapolation using the IPS.

The FPS is complicated by the need to establish the virtual surface and, on that surface, a virtual mesh. For the 2D applications of Aerodynamic Panel Methods, the virtual mesh for the interpolation surface is simply the planar region defined by the CAEROi entry. A simple n x m mesh of points can be used to subdivide the region into finite elements. The geometries of these planes are such that each FE is almost certainly going to have acceptable geometry. Furthermore, since only normal forces are mapped, the structural points can be projected onto the virtual surface without any complications (noting that the aerodynamic points are on the interpolation surface).

Consider a planar trapezoidal surface that lies in a local x-y plane and that is divided into a series of finite elements as shown in Figure 2-3. We want to use this FE plate to interpolate between a set of n structural points and m aerodynamic points, which are not necessarily coincident with the N virtual mesh points.

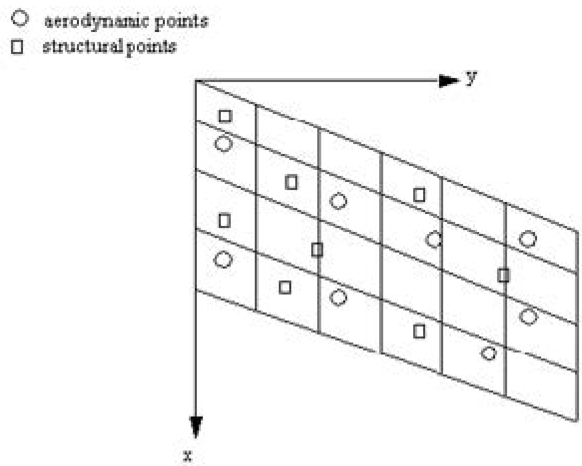

Figure 2-3 Two Dimensional Finite Surface Spline

Consider a 4-noded quadrilateral element in which the normal displacement, $w = w(x, y)$, and the rotations, $\theta = \theta(x, y)$, about the *x* axis and $\phi = \phi(x, y)$, about the *y* axis are given by:

$$\{r\} = [\Omega]\{u^e\} \tag{2-78}$$

$$\{r\} = \begin{Bmatrix} w \\ \theta \\ \phi \end{Bmatrix};\ [\Omega] = \begin{Bmatrix} \lfloor \omega \rfloor \\ \lfloor \omega_{,x} \rfloor \\ \lfloor \omega_{,y} \rfloor \end{Bmatrix};\ \{u^e\} = \lfloor w_1\ \theta_1\ \phi_1 \ldots \phi_4 \rfloor^T \tag{2-79}$$

and where the angles satisfy the relations

$$\theta = \frac{dw}{dy};\quad \phi = \frac{dw}{dx} \tag{2-80}$$

The shape functions, $\lfloor \omega \rfloor$, are a *1x12* row matrix used to interpolate the displacement field within the element in terms of the nodal displacements, $\{u^e\}$. Experience documented in Appa, 1989 suggests that a C^1continuous shape function is the preferred choice with the angular rotations given by (2-80) rather than by independent shape functions. For each element in the entire virtual FE mesh, a boolean connectivity matrix, $[B]$, is developed to relate the element nodal displacements to the overall FE mesh displacements:

$$\{u^e\}_i = [B]_i\{u\} \tag{2-81}$$

Given Equations (2-81) and (2-78), the displacement at each of the structural points and each of the aerodynamic points may be related to the virtual mesh displacements as:

$$[\Psi_s] = \begin{bmatrix} [\Omega]^s_1 & [B]_1 \\ [\Omega]^s_2 & [B]_2 \\ \dots & \dots \\ [\Omega]^s_n & [B]_n \end{bmatrix} \tag{2-82}$$

and

$$[\Psi_a] = \begin{bmatrix} [\Omega]^a_1 & [B]_1 \\ [\Omega]^a_2 & [B]_2 \\ \dots & \dots \\ [\Omega]^a_m & [B]_m \end{bmatrix} \tag{2-83}$$

and the structural point displacements and aerodynamic point displacements can be expressed as functions of the virtual FE mesh displacements:

$$\{u_s\} = [\Psi_s]\{u\} \tag{2-84}$$

$$\{u_a\} = [\Psi_a]\{u\} \tag{2-85}$$

Since the virtual surface described by the FE mesh is required to pass through the set of independent (structural) points, a penalty method can be used to express the equilibrium state of the virtual surface:

$$[K]\{u\} + [\alpha][\Psi_s]^T([\Psi_s]\{u\} - \{u_s\}) = 0 \tag{2-86}$$

where $[\alpha]$ represents an invertible, diagonal weighting matrix to scale the elements of $[K]$ and $[\Psi_s]^T[\Psi_s]$

Using (2-86) to solve for the virtual mesh displacements, $\{u\}$ yields:

$$\{u\} = \left\{[\alpha]^{-1}[K] - [\Psi_s]^T[\Psi_s]\right\}^{-1}[\Psi_s]\{u_s\} = [A]^{-1}[\Psi_s]\{u_s\} \tag{2-87}$$

and substituting into (2-85), the desired splining relationship can be found directly:

$$[G_{as}] = [\Psi_a]\left\{[\alpha]^{-1}[K] + [\Psi_s]^T[\Psi_s]\right\}^{-1}[\Psi_s]^T \tag{2-88}$$

The virtual surface stiffness properties are such that our requirements for equilibrium preservation are satisfied and virtual work principles allow us to use the transpose of (2-88) as the force transform. Spring attachments are available in this method by adding flexibilities to the diagonals of the matrix $[A]$ in (2-87). Three such flexibilities are possible: k_w, k_θ and k_ϕ. but a single value has been used for all three in the actual implementation.

Experience based on the implementation of Appa, 1989, has shown that reasonable behavior for 2D aeroelastic applications is obtained if the virtual mesh is constructed on the plane of the CAEROi within the superscribing quadrilateral that contains all the aerodynamic points and the projected structural points. This represents an improvement over the IPS without requiring the complexity of the triangular degenerate case.

The Constraint Spline

The constraint spline in MSC Nastran is simply a multipoint constraint useful for including control surfaces in aeroelastic analyses. The constraint has the form

$$u_d = \sum_i A_i u_i \tag{2-89}$$

where u_d is the value of the dependent u_k component, and u_i is the displacement at grid G_i with component C_i. The A_i coefficients are user defined.

Radial Basis Functions

Radial Basis Functions are a concept developed notably by investigations to achieve a simple, smooth interpolation function (See Beckert, R. L and Wendland, 2001). MSC has provided an implementation of these methods as outlined below, but does not have enough experience to quantify the benefits. Mention is made of them here since they are exposed in a number of the surface and linear splines.

Radial basis functions are interpolation functions that depend on the distance only, i.e.

$$\varphi_v(\mathbf{x}, \mathbf{x}_v) = \varphi_v(r) \text{ where } r = \|x - x_v\| \tag{2-90}$$

An important class of radial basis function is the class of function that have local support, i.e.

$$\phi_v(r) = 0 \text{ for r > r}_c \tag{2-91}$$

where r_c is a core radius specified by the user.

In MSC implementation, Wendland functions (Beckert, R. L and Wendland, 2001) are used. The C^0 function is defined as

$$\phi\left(\frac{r}{r_C}\right) = \left(1 - \frac{r}{r_C}\right)_+ \tag{2-92}$$

and the C^2 function is defined as

$$\phi\left(\frac{r}{r_C}\right) = \left(1 - \frac{r}{r_C}\right)_+^4\left(4\frac{r}{r_C} + 1\right) \tag{2-93}$$

where

$$(y)_+^n = \begin{cases} y^n & \text{if } y > 0 \\ 0 & \text{if } y \leq 0 \end{cases} \tag{2-94}$$

The associated functions $\psi_\mu(x)$ read (Beckert, R. L and Wendland, 2001)

$$\psi_1(x) = 1\,,\ \psi_2(x) = x_1\,,\ \psi_3(x) = x_2\,,\ \psi_4(x) = x_3 \tag{2-95}$$

Rigid Body Spline

In the basic coordinate system, the displacements (u_x, u_y, u_z) and rotations ϕ_x, ϕ_y, ϕ_z of a grid point with coordinates (x, y, z) due to a rigid body motion composed of a translation (t_x, t_y, t_z) and a rotation ψ_x, ψ_y, ψ_z can be computed from

$$\begin{bmatrix} u_x \\ u_y \\ u_z \\ \hline \phi_x \\ \phi_y \\ \phi_z \end{bmatrix}_B = \left[\begin{array}{ccc|ccc} 1 & 0 & 0 & 0 & z & -y \\ 0 & 1 & 0 & -z & 0 & x \\ 0 & 0 & 1 & y & -x & 0 \\ \hline 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{array}\right] \begin{bmatrix} t_x \\ t_y \\ t_z \\ \hline \psi_x \\ \psi_y \\ \psi_z \end{bmatrix} \tag{2-96}$$

If the grid point has a local displacement coordinate system, displacements and rotations need be transformed. The resulting equation reads

$$\begin{bmatrix} \bar{u}_x \\ \bar{u}_y \\ \bar{u}_z \\ \bar{\phi}_x \\ \bar{\phi}_y \\ \bar{\phi}_z \end{bmatrix} = \begin{bmatrix} c_{xx} & c_{xy} & c_{xz} & 0 & 0 & 0 \\ c_{yx} & c_{yy} & c_{yz} & 0 & 0 & 0 \\ c_{zx} & c_{zy} & c_{zz} & 0 & 0 & 0 \\ 0 & 0 & 0 & c_{xx} & c_{xy} & c_{xz} \\ 0 & 0 & 0 & c_{yx} & c_{yy} & c_{yz} \\ 0 & 0 & 0 & c_{zx} & c_{zy} & c_{zz} \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 & z & -y \\ 0 & 1 & 0 & -z & 0 & x \\ 0 & 0 & 1 & y & -x & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} t_x \\ t_y \\ t_z \\ \psi_x \\ \psi_y \\ \psi_z \end{bmatrix} \tag{2-97}$$

Equations (2-96) or (2-97) can be used to compute the displacements and rotations at the aerodynamic grid points from the rigid body motion (t_x, t_y, t_z; ψ_x, ψ_y, ψ_z). To determine the rigid body motion, six degrees of freedom need be defined such that the corresponding rows in equations (2-96) or (2-97) are linearly independent. Then, the matrix built from these rows can be inverted. This inverse matrix allows to compute the rigid body motion from any motion given at the selected six degrees of freedom.

Spline Blending

If aerodynamic grid points are part of several splines, then unique displacements at these grid points can be defined by building weighted averages of the contributions of the different splines. This blending can be described by a blending matrix $B_{\tilde{K}R}$ that allows to compute the displacements at the K-set degrees of freedom from the sum of all aerodynamic degrees of freedom involved in splining, i.e.

$$u_{\tilde{K}} = B_{\tilde{K}R} u_R \tag{2-98}$$

The final aerodynamic displacements u_K are then obtained by reordering, i.e.

$$u_K = T_{K\tilde{K}} u_{\tilde{K}} \tag{2-99}$$

The blending matrix $B_{\tilde{K}R}$ can be built recursively from binary blendings between two splines, creating a new third spline.

Consider two splines which have some common aerodynamic grid points. Then, the displacements at the K-set degrees of freedom are obtained from

$$u_{\tilde{K}} = B_{\tilde{K}R1} u_{R1} + B_{\tilde{K}R2} u_{R2} \tag{2-100}$$

where, $B_{\tilde{K}R1}$ and $B_{\tilde{K}R2}$ are very sparse matrices containing the blending functions. With

$$B_{\tilde{K}R} = [B_{\tilde{K}R1} \quad B_{\tilde{K}R2}] \text{ and } u_{\tilde{K}} = \begin{bmatrix} u_{R1} \\ u_{R2} \end{bmatrix} \tag{2-101}$$

Spline Relaxation

In spline relaxation, the displacements of a spline are modified so that, on the boundary to an adjacent spline, the displacements of the adjacent spline are matched. Modifications are done only in the vicinity of the boundary, defined by a reference length D_{ref}.

The boundary of the adjacent spline is defined by a set of aerodynamic grid points of the adjacent spline. These grid points may or may not be coincident with the aerodynamic grid points of the spline to be modified.

The first task in spline relaxation is to find the location on the boundary that is closest to the aerodynamic grid point processed. This can be done as follows:

1. Find that aerodynamic grid point of the adjacent spline that is closest to the grid point processed.
2. Find the aerodynamic elements connected to the aerodynamic grid point found in step 1.
3. Find all grid points the elements found in step 2 are connected to that are on the boundary.
4. Among the grid points found in step 3, find the one that is closest to the grid point processed.
5. On the straight line connecting the grid points found in steps 1 and 4, find the position that is closest to the grid point processed.

Once the closest location has been found, the distance r is known. Also, displacements u2 can be determined by interpolating between the two adjacent grid points. The displacements of the grid point processed are modified according to

$$u_{1mod} = u_1 + f\left(\frac{r}{D_{ref}}\right)(u_2 - u_1) \tag{2-102}$$

where

$$f(x) = \begin{cases} 1 - x & \text{if } x \le 1 \\ 0 & \text{if } x > 1 \end{cases} \tag{2-103}$$

Equation (2-102) is a linear relation between two splines. Thus, spline relaxation can be implemented by premultiplying the spline matrix obtained after spline blending by a relaxation matrix.

User Defined Spline

A final spline methodology implemented in MSC Nastran is the Externally-Evaluated spline invoked by the SPLINEX bulk data entry and that invokes a user defined procedure as documented in the Multiple Computed Architecture Support section of the *MSC Nastran Installation and Operations Guide*.

Theory of Three DOF or Six DOF Surface Splines

This final surface spline provides for up to six DOF's (degrees of freedom) on both the structural and aerodynamic meshes. (Conceptually, this spline could be use to spline from one structural mesh to another, but this is not a standard MSC Nastran capability). The spline creates a small virtual surface by invoking a set of structural or aerodynamic elements. At each node on the virtual surface, a companion "bush" node is defined coincident to it and the two nodes are connected by a bush element that has stiffness terms defined by user-defined parameters with a default value of 1.0. RBE3 elements are then used to connect the virtual surface to the independent structural DOF's and the dependent aerodynamic DOF's. Interpolants are then created each of the independent DOF's and the spline matrices are created using equations that are similar to those provided for the other spline methods. The Guidelines section of Chapter 3 and the *MSC Nastran Quick Reference Guide* provides additional information on supplying the parameters that are available for defining this spline.

Theory of Six DOF Linear Splines

This final linear spline provides for up to six DOF's (degrees of freedom) on both the structural and aerodynamic meshes. The spline creates a small virtual beam by specifying its axis. Independent structural nodes are connected to the virtual beam via RBE3 elements which attach to a "bush" node which in turn connects to a coincident node on the beam using a bush element with user defined stiffness values. Aerodynamic dof's are then connected to the beam via RBE2 elements. Interpolants are then created each of the independent DOF's and the spline matrices are created using equations that are similar to those provided for the other spline methods. The Guidelines section of Chapter 3 and the *MSC Nastran Quick Reference Guide* provides additional information on supplying the parameters that are available for defining this spline. The Figure 2-4 provides a visual depiction of a typical application of applying the spline technique to link structural and aerodynmic meshes that model nacelle.

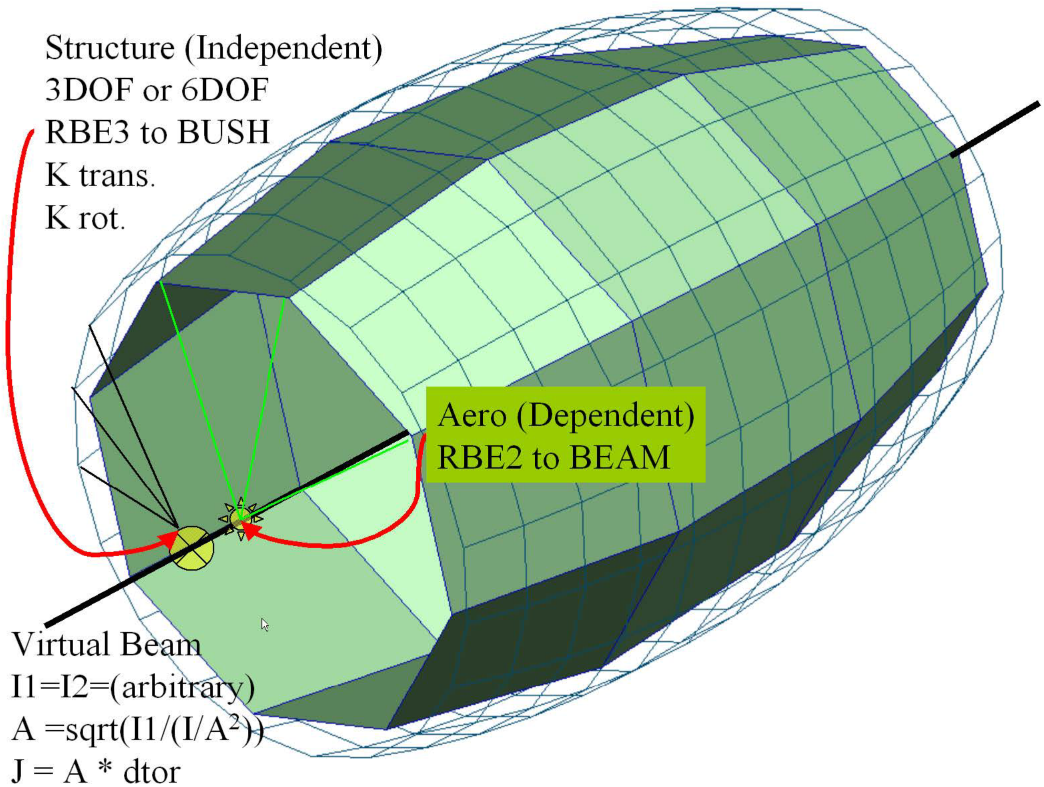

Figure 2-4 Linear Six DOF Spline Application

Static Aeroelasticity

Static (or quasi-steady) aeroelastic problems deal with the interaction of aerodynamic and structural forces on a flexible vehicle that results in a redistribution of the aerodynamic loading as a function of airspeed. The aerodynamic load redistribution and consequent internal structural load and stress redistributions are of concern to the structural analyst. The possibility of a static aeroelastic instability, (that is, divergence) is also of concern to the structural analyst. The aerodynamic load redistribution and consequent modifications to aerodynamic stability and control derivatives are of interest to the aerodynamicist and the control systems analyst. The static aeroelastic capability in MSC Nastran addresses these needs by the computation of aircraft trim conditions, with subsequent recovery of structural responses, aeroelastic stability derivatives, and static aeroelastic divergence dynamic pressures.

Generation of Aerodynamic Matrices

The aerodynamic equations of Internal Aerodynamic Theories form the basis of the aerodynamic computations required for static aeroelastic analysis with some special purpose modifications made for the MSC Nastran implementation.

For static aeroelasticity, the downwash relation of (2-2) becomes:

$$\{w_j\} = [D_{jk}]\{u_k\} + [D_{jx}]\{u_x\} + \left\{w_j^g\right\} \tag{2-104}$$

where:

$\{w_j\}$	= downwash vector (for example, angles of attack)
$\{u_k\}$	= vector of aerodynamic displacements (deformations)
$\{u_x\}$	= vector of "extra aerodynamic points" used to describe, for example, aerodynamic control surface deflections and overall rigid body motions
$\left\{w_j^g\right\}$	= represents an initial static aerodynamic downwash. It includes, primarily, the static incidence distribution that may arise from an initial angle of attack, camber, or washout (twist).
$[D_{jk}]$	= substantial derivative matrix for the aerodynamic displacements. This is the D_{jk}^1 term of (2-2) and the D_{jk}^2 term is not used for this quasi-steady analysis
$[D_{jx}]$	= substantial derivative matrix for the extra aerodynamic points

The theoretical aerodynamic pressures are given by (2-20).

$$\{f_j\} = \bar{q}[A_{jj}]^{-1}\{w_j\} \tag{2-105}$$

and the aerodynamic forces, based on (2-20) and (2-21), can be written

$$\{P_k\} = \bar{q}[W_{kk}][S_{kj}][A_{jj}]^{-1}\{w_j\} + \bar{q}[S_{kj}]\left\{f_j^e/\bar{q}\right\} \tag{2-106}$$

where all the terms have been defined in Internal Aerodynamic Theories.

The vector of aerodynamic extra points specifies the values of aerodynamic trim variables. MSC Nastran has a number of predefined variables, including incidence angles (α and β), roll, pitch, and yaw rates (p, q, and r) and two translational ($\ddot{u}_2$ and $\ddot{u}_3$) and three rotational ($\dot{p}$, $\dot{q}$ and $\dot{r}$) accelerations. The DJX matrix, then, provides the vector of downwash velocities for unit values of these aerodynamic extra points. Note that accelerations do not result in any downwash for the quasi-steady assumption so that the corresponding columns of the DJX matrix are null.

Static Aeroelastic Equations of Motion

The aerodynamic forces are transferred to the structure using the spline matrix in (2-22) and (2-25) reduced to the a-set to form an aerodynamic influence coefficient matrix, Q_{aa}, which provides the forces at the structural grid points due to structural deformations

$$[Q_{aa}] = [G_{ka}]^T[W_{kk}][S_{kj}][A_{jj}]^{-1}[D_{jk}][G_{ka}] \tag{2-107}$$

and a second matrix, Q_{ax}, which provides forces at the structural grid points due to unit deflections of the aerodynamic extra points:

$$[Q_{ax}] = [G_{ka}]^T[W_{kk}][S_{kj}][A_{jj}]^{-1}[D_{jx}] \tag{2-108}$$

The complete equations of motion in the a-set degrees of freedom require

K_{aa}	Structural stiffness matrix
M_{aa}	Structural mass matrix
P_a	Vector of applied loads (for example, mechanical, thermal, and gravity loads plus aerodynamic terms due to user input pressures and/or downwash velocities)

The a-set equations are then:

$$[K_{aa} - \bar{q}Q_{aa}]\{u_a\} + [M_{aa}]\{\ddot{U}_a\} = \bar{q}[Q_{ax}]\{u_x\} + \{P_a\} \tag{2-109}$$

This is the basic set of equations used for static aeroelastic analysis. In the general case, rigid body motions are included in the equations to represent the free-flying characteristic of an air vehicle. This is addressed in MSC Nastran by a requirement that the user identify reference degrees of freedom equal in number to the number of rigid body motions using the SUPORT Bulk Data entry. (2-109) is then partitioned into r-set (supported) and l-set (left over) degrees of freedom yielding

$$\begin{bmatrix} K^a_{ll} & K^a_{lr} \\ K^a_{rl} & K^a_{rr} \end{bmatrix} \begin{Bmatrix} u_l \\ u_r \end{Bmatrix} + \begin{bmatrix} M_{ll} & M_{lr} \\ M_{rl} & M_{rr} \end{bmatrix} \begin{Bmatrix} \ddot{u}_l \\ \ddot{u}_r \end{Bmatrix} = -\begin{bmatrix} K^a_{lx} \\ K^a_{rx} \end{bmatrix} \{u_x\} + \begin{Bmatrix} P_l \\ P_r \end{Bmatrix} \tag{2-110}$$

where the notation

$$[K^a_{aa}] = [K_{aa} - \bar{q}Q_{aa}]$$

$$[K^a_{ax}] = -\bar{q}[Q_{ax}]$$

has been introduced.

At this point the MSC Nastran implementation of aeroelastic analysis introduces a mathematical technique that is based on the MSC Nastran inertia relief analysis without aeroelastic effects. The technique entails multiplying the first row of (2-110) by D^T and adding the result to the second row, where

$$D = -[K_{ll}]^{-1}[K_{lr}] \tag{2-111}$$

is known as the rigid body mode matrix and can be shown to be only a function of the geometry of the model. The resulting set of equations is then

$$\begin{bmatrix} K^a_{ll} & K^a_{lr} \\ (D^T K^a_{ll} + K^a_{rl}) & (D^T K^a_{lr} + K^a_{rr}) \end{bmatrix} \begin{Bmatrix} u_l \\ u_r \end{Bmatrix} + \begin{bmatrix} M_{ll} & M_{lr} \\ (D^T M_{ll} + M_{rl}) & (D^T M_{lr} + M_{rr}) \end{bmatrix} \begin{Bmatrix} \ddot{u}_l \\ \ddot{u}_r \end{Bmatrix} \tag{2-112}$$

$$= -\begin{bmatrix} K^a_{lx} \\ D^T K^a_{lx} + K^a_{rx} \end{bmatrix} \{u_x\} + \begin{Bmatrix} P_l \\ D^T P_l + P_r \end{Bmatrix}$$

If there were no aerodynamic terms, the $D^T K_{ll} + K_{rl}$ and $D^T K_{lr} + K_{rr}$ would sum to zero so that the second row of equations could be solved for $\{\ddot{u}_r\}$. With the aerodynamic coupling, this simplification is not possible.

Note:	$D^T K_{ll} + K_{rl} = 0$ from the definition of D given in (2-111). Note that $D^T K_{lr} + K_{rr} = 0$ because this represents the work performed on the structure when it undergoes a rigid body displacement.

It is seen that (2-112) contains $nl + nr$ equations with $2(nl + nr)$ undetermined quantities, where nl, nr, and nx are the number of degrees of freedom in the l and r sets and the number of aerodynamic extra points, respectively.

The undetermined accelerations can be directly specified using two relations. The first relation comes from the assumption of quasi-steady equilibrium and specifies that

$$\{\ddot{u}_l\} = [D]\{\ddot{u}_r\} \tag{2-113}$$

where $[D]$ is the rigid body mode matrix of (2-111), and (2-112) simplifies to

$$\begin{bmatrix} K^a_{ll} & K^a_{lr} \\ (D^T K^a_{ll} + K^a_{rl}) & (D^T K^a_{lr} + K^a_{rr}) \end{bmatrix} \begin{Bmatrix} u_l \\ u_r \end{Bmatrix} + \begin{bmatrix} M_{ll} D \; M_{lr} \\ m_r \end{bmatrix} \{\ddot{u}_r\} \tag{2-114}$$

$$= -\begin{bmatrix} K^a_{lx} \\ D^T K^a_{lx} + K^a_{rx} \end{bmatrix} \{u_x\} + \begin{Bmatrix} P_l \\ D^T P_l + P_r \end{Bmatrix}$$

where $[mr] = [M_{rr} + M_{rl}D + D^T M_{lr} + D^T M_{ll} D]$ is the "total" mass matrix relative to the u_r points.

The second relation recognizes that the $\{\ddot{u}_r\}$ structural accelerations are related to the aerodynamic extra points $\{u_x\}$ via

$$\{\ddot{u}_r\} = [TR]^T [TRX] \{u_x\} \tag{2-115}$$

where TRX is a Boolean matrix that selects accelerations from the aerodynamic extra points and $[TR]^T$ is a matrix that transforms accelerations from the aerodynamic reference point to the "supported" degrees of freedom. This second matrix is a function of only the geometry of the model.

The further solution of the static aeroelastic equations is dependent on the type of analysis required. The remainder of the section is divided into four subsections that treat (1) restrained analysis for trim and stability derivative analysis, (2) unrestrained stability derivative analysis, (3) rigid stability derivatives, and (4) divergence analysis.

Restrained Analysis

Significant simplification is made by assuming that the $\{u_r\}$ terms can be set to zero with the remaining displacements then computed relative to this assumption. Therefore, setting $u_r = 0$ in (2-114), and solving for u_l from the first row gives:

$$\{u_l\} = [K^a_{ll}]^{-1} [-[M_{ll}D + M_{lr}]\{\ddot{u}_r\} - [K^a_{lx}]\{u_x\} + \{P_l\}] \tag{2-116}$$

This is then substituted into the second row of (2-114) and the relationship for $\{\ddot{u}_r\}$ in terms of $\{u_x\}$ of (2-115) is used to give nr equations with only the u_x quantities undetermined:

$$[ZZX]\{u_x\} = \{PZ\} \tag{2-117}$$

where:

$$[ZZX] = [m_r][TR]^T[TRX] + -[D^T K_{ll}^a + K_{rl}^a][K_{ll}^a]^{-1}[M_{ll}D + M_{lr}][TR]^T[TRX] \qquad (2\text{-}118)$$
$$-[D^T K_{lx}^a + K_{rx}^a][D^T K_{ll}^a + K_{rl}^a][K_{ll}^a]^{-1}[K_{lx}^a]$$

$$[PZ] = [D]^T\{P_l\} + \{P_r\} - [D^T K_{ll}^a + K_{rl}^a][K_{ll}^a]^{-1}\{P_l\} \qquad (2\text{-}119)$$

The solution of (2-117) for u_x requires that the equation be augmented by user input relations that specify all but nr terms in the u_x vector. These user specifications can be done by either specifying u_x values directly or by specifying a linkage that makes a term (or terms) in the u_x vector dependent on an independently varying term. The augmented trim equation then has the form:

$$\begin{bmatrix} ZZX \\ IP \\ AEL \end{bmatrix}\{u_x\} = \begin{Bmatrix} PZ \\ Y \\ O \end{Bmatrix} \qquad (2\text{-}120)$$

where IP is a pseudo-identity matrix with as many rows as there are user-specified constraints on the values of u_x terms. The IP matrix has ones in the row and columns corresponding to the constrained variables and zero elsewhere. The Y vector contains the values of the user-specified constraints. The AEL matrix contains any user-specified relationships between (or among) aerodynamic extra points. (2-120) can then be solved for the remaining terms in the u_x vector.

Once the u_x vector has been evaluated, $\{\ddot{u}_l\}$ and $\{u_l\}$ can be recovered using (2-115), and (2-116), respectively. Standard MSC Nastran data recovery techniques are used to compute user-requested values of displacements, stresses, etc.

The user may also request pressures and forces on the aerodynamic boxes or elements. These terms are calculated using (2-105) for the pressures and (2-106) for the forces.

Stability derivatives are also calculated using the ZZX and PZ matrices with some modifications. For stability derivatives associated with aerodynamic extra points, dimensional stability derivatives are obtained from

$$[KRZX] = [ZZX] - [m_r][TR]^T[TRX] \qquad (2\text{-}121)$$

Stability Derivatives. The second term on the right-hand side represents removing the vehicle accelerations from the ZZX matrix. Nondimensional stability derivatives are then calculated using:

$$\begin{Bmatrix} C_x \\ C_y \\ C_z \\ C_{mx} \\ C_{my} \\ C_{mz} \end{Bmatrix} = \frac{1}{\bar{q}S}[NDIM][TR][KRZX] \tag{2-122}$$

where S is the reference area of the vehicle, TR transforms forces from the support location to the aerodynamic reference point and

$$[NDIM] = \begin{bmatrix} 1.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 \\ 0.0 & 1.0 & 0.0 & 0.0 & 0.0 & 0.0 \\ 0.0 & 0.0 & 1.0 & 0.0 & 0.0 & 0.0 \\ 0.0 & 0.0 & 0.0 & 1.0/b_{ref} & 0.0 & 0.0 \\ 0.0 & 0.0 & 0.0 & 0.0 & 1.0/c_{ref} & 0.0 \\ 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 1.0/b_{ref} \end{bmatrix} \tag{2-123}$$

where c_{ref} and b_{ref} are the reference chord and span, respectively.

The intercept coefficients are computed using only partitions of the PZ vector that are dependent on $\bar{q}$, that is, terms associated with user input downwashes and user input pressure coefficients. This means that applied mechanical, thermal, and gravity loads are neglected in the following calculation:

$$\begin{Bmatrix} C_x \\ C_y \\ C_z \\ C_{mx} \\ C_{my} \\ C_{mz} \end{Bmatrix}_0 = \frac{1}{\bar{q}S}[NDIM][TR][PZ] \tag{2-124}$$

Unrestrained Stability Derivatives

The stability derivatives of the previous section were computed under the assumption of $\{u_r\} = 0$. This calculates these quantities in a structural axis system that is dependent on the arbitrary selection of the support

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point location. The stability derivatives of an unrestrained vehicle must be invariant with the selection of the support point location. This invariance is obtained by introducing a mean axis system. The characteristic of the mean axis is that deformations of the structure about it occur such that there is neither movement of the center of gravity nor rotation of the principal axes of inertia. Stated another way, the displacements in the mean axis system are orthogonal to the rigid body modes of the vehicle. In terms of the rigid body mode matrix $[D]$ and the mass matrix of the system $[M_{aa}]$, the mean axis constraint is defined by

$$\begin{bmatrix} D \\ I \end{bmatrix}^T \begin{bmatrix} M_{ll} & M_{lr} \\ M_{rl} & M_{rr} \end{bmatrix} \begin{Bmatrix} u_l \\ u_r \end{Bmatrix} = 0 \tag{2-125}$$

or

$$[D^T M_{ll} + M_{rl}]\{u_l\} + [D^T M_{lr} + M_{rr}]\{u_r\} = 0 \tag{2-126}$$

(2-114) and (2-126) can be combined to give an overall system of equations:

$$\begin{bmatrix} K^a_{ll} & K^a_{lr} \\ D^T M_{ll} + M_{rl} & D^T M_{lr} + M_{rr} \\ D^T K^a_{ll} + K^a_{rl} & D^T K^a_{lr} + K^a_{rr} \end{bmatrix} \begin{Bmatrix} u_l \\ u_r \end{Bmatrix} + \begin{bmatrix} M_{ll} D + M_{lr} \\ 0 \\ m_r \end{bmatrix} \{\ddot{u}_r\} \tag{2-127}$$

$$= -\begin{bmatrix} K^a_{lx} \\ 0 \\ D^T K^a_{lx} + K^a_{rx} \end{bmatrix} \{u_x\} + \begin{Bmatrix} P_l \\ 0 \\ D^T P_l + P_r \end{Bmatrix}$$

The first row of this equation can be solved for u_l in terms of u_r and $\ddot{u}_r$ and u_x

$$\begin{aligned} \{u_l\} &= -[K^a_{ll}]^{-1}[[K^a_{ll}]\{u_r\} + [M_{ll}D + M_{lr}]\{\ddot{u}_r\} + [K^a_{lx}]\{u_x\} - INTL] \\ &\equiv -[AMLR]\{\ddot{u}_r\} - [ARLR]\{u_r\} - [ALX]\{u_x\} + \{UINTL\} \end{aligned} \tag{2-128}$$

where the ARLR, AMLR, ALX, and UINTL terms can be inferred. The INTL vector is the aerodynamic related portion of the P_l vector.

The expression for u_l of (2-128) can be placed in the second row of (2-127) to give

$$[M2RR]\{u_r\} + [M3RR]\{\ddot{u}_r\} + [K3LX]\{u_x\} = -[TMP1] \tag{2-129}$$

where:

$$[M2RR] = [D^T M_{lr} + M_{rr}] - [D^T M_{ll} + M_{rl}][ARLR]$$

$$[M3RR] = -[D^T M_{ll} + M_{rl}][AMLR]$$

$$[K3LX] = -[D^T M_{ll} + M_{rl}][ALX]$$

$$[TMP1] = [D^T M_{ll} + M_{rl}]\{UINTL\}$$

(2-129) is solved for u_r in terms of $\ddot{u}_r$ and u_x to give:

$$\{u_r\} = -[M4RR]\{\ddot{u}_r\} - [K4LX]\{u_x\} - \{TMP2\} \tag{2-130}$$

where:

$$[M4RR] = [M2RR]^{-1}[M3RR]$$

$$[K4LX] = [M2RR]^{-1}[K3LX]$$

$$\{TMP2\} = [M2RR]^{-1}\{TMP1\}$$

If the expression for u_l from (2-128) is placed in the third row of (2-127), then:

$$[K2RR]\{u_r\} + [MSRR - KAZL \cdot AMLR]\{\ddot{u}_r\} + [KARZX]\{u_x\} = \{IPZ\} \tag{2-131}$$

where:

$$[K2RR] = -[D^T K^a_{ll} + K^a_{rl}][ARLR] + [D^T K^a_{lr} + K^a_{rr}]$$

$$MSRR = m_r$$

$$KAZL = D^T K^a_{ll} + K^a_{rl}$$

$$KARZX = KAZL - KAXL \cdot ALX$$

$$\{IPZ\} = \{INTZ\} - [D^T K^a_{ll} + K^a_{rl}]\{UINTL\}$$

where: $\{INTZ\}$ is the aerodynamic portion of $\left\{D^T P_l + P_r\right\}$

Next, the u_r expression of (2-130) is placed in (2-131) to give:

$$[MIRR]\{\ddot{u}_r\} + [KR1ZX]\{u_x\} = \{IPZF\} \tag{2-132}$$

where:

$$[M5RR] = -[K2RR][M4RR] + [MSRR]$$
$$[MIRR] = -[KAZL][AMLR] + [M5RR]$$
$$[KR1ZX] = -[K2RR][K4LX] + [KARZX]$$
$$\{IPZF\} = [K2RR]\{TMP2\} + \{IPZ\}$$

The stability derivatives require an equation that pre multiplies the $\ddot{u}_r$ term by the rigid body mass matrix.

This is achieved by pre multiplying (2-132) by $[MSRR][MIRR]^{-1}$

$$[MSRR]\{\ddot{u}_r\} = [Z1ZX]\{u_x\} + \{IPZF2\} \tag{2-133}$$

where:

$$\{IPZF1\} = [MIRR]^{-1}\{IPZF\}$$
$$\{IPZF2\} = [MSRR]\{IPZF1\}$$
$$[KR2ZX] = -[MIRR]^{-1}[KR1ZX]$$
$$[Z1ZX] = [MSRR][K2RZX]$$

In a manner similar to the restrained case, the unrestrained stability derivatives can be obtained using

$$\left.\begin{array}{l}\begin{bmatrix} C_x \\ C_y \\ C_z \\ C_{mx} \\ C_{my} \\ C_{mz} \end{bmatrix} = \dfrac{1}{\bar{q}S}[NDIM][TR][Z1ZX] \\ \begin{Bmatrix} C_x \\ C_y \\ C_z \\ C_{mx} \\ C_{my} \\ C_{mz} \end{Bmatrix}_0 = \dfrac{1}{\bar{q}S}[NDIM][TR]\{IPZF2\}\end{array}\right\} \tag{2-134}$$

Rigid Stability Derivatives and Mean Axis Rotations

This subsection briefly provides a theoretical description of several data blocks that are used to provide output to the user. Two sets of rigid stability derivatives are printed out. These are stability derivatives that are computed when elastic deformations are neglected. The first set of rigid derivatives are denoted as "unsplined" and are the values obtained directly from the aerodynamic calculations before they have been transferred to the structure. The dimensional matrix that contains these derivatives is

$$[RSTAB] = \bar{q}[SRKT]^T[Q_{kx}]$$

where:

$$[Q_{kx}] = [W_{kk}][S_{kj}][A_{jj}]^{-1}[D_{jx}]$$

[see (2-108)], and $SRKT$ is a matrix that sums forces acting on each of the aerodynamic boxes or elements to the supported degrees of freedom. This matrix is only a function of the geometry of the aerodynamic model and the locations of the support degrees of freedom.

The intercept stability dimensional derivatives are computed using

$$\{RINT\} = \bar{q}[SRKT]^T\left([W_{kk}][S_{kj}][A_{jj}]^{-1}\{w_j\} + [S_{kj}]\left\{f_j^e/\bar{q}\right\}\right) \tag{2-135}$$

Similar expressions are available to the splined rigid stability derivatives and intercepts

$$[KSAZX] = [D^T K^a_{lx} + K^a_{rx}] \tag{2-136}$$

$$\{INTZ\} = [G_{ka}]^T \{RINT\} \tag{2-137}$$

Nondimensionalization of these matrices is performed in a fashion similar to that given in (2-122) for stability derivatives and (2-124) for intercept values.

The availability of these rigid terms is useful in several ways. A comparison between the splined and unsplined derivatives provides an assessment of the quality of the splining. If the numbers differ significantly, this may indicate that not all aerodynamic elements have been transferred to the structure. This may be the user's intent or it may indicate a user error. If the two sets of rigid numbers bear little resemblance to one another, a serious splining error has been made. The guidelines of Aeroelastic Modeling should be consulted to determine if there is a modeling error.

Similarly, experience should allow the user to assess the reasonableness of the flexible results when compared with the rigid numbers. Large differences indicate large structural deformations and may point up conditions such as local weaknesses in the structure, an aerodynamic model displaced from the structural model, or errors in the input of the flight condition.

The rotations of the mean axes relative to the structural axes through the support points are required when restrained aeroelastic coefficients (stability derivatives and intercept coefficients) are used in the equations of motion [see Rodden and Love (1985) [Reference 51]]. The deflections of the mean axes relative to the origin of the structural axes are derived as follows.

The grid point deflections relative to the mean axes $\{\bar{u}_l\}$ are related to the deflections of the SUPORT points $\{\bar{u}_r\}$ through the rigid body mode matrix $[D]$ (see Figure 2-5).

$$\{\bar{u}_l\} = \{u_l\} + [D]\{\bar{u}_r\} \tag{2-138}$$

The requirement for the mean axes is that deformation occurs about them such that the center of gravity does not move and the axes do not rotate. In terms of the rigid body mode matrix and the mass matrix, this condition is expressed by

$$\begin{bmatrix} D \\ I \end{bmatrix}^T \begin{bmatrix} M_{ll} & M_{lr} \\ M_{rl} & M_{rr} \end{bmatrix} \begin{Bmatrix} \bar{u}_l \\ \bar{u}_r \end{Bmatrix} = 0 \tag{2-139}$$

(2-138) and (2-139) lead to

$$\{\bar{u}_r\} = -[m_r]^{-1}[D^T M_{ll} + M_{rl}]\{u_l\} \tag{2-140}$$

Introducing (2-116) yields

$$\{\bar{u}_r\} = -[m_r]^{-1}[D^T M_{ll} + M_{rl}][K_{ll}^a]^{-1}$$
$$([M_{ll}D + M_{lr}]\{\ddot{u}_r\} + [K_{lx}^a]\{u_x\} - \{P_l\}) \tag{2-141}$$

and with (2-115) we finally obtain

$$\{\bar{u}_r\} = -[m_r]^{-1}[D^T M_{ll} + M_{rl}][K_{ll}^a]^{-1}[([M_{ll}D$$
$$+ M_{lr}][TR]^T[TRX] + [K_{lx}^a])\{u_x\} - \{P_l\}] \tag{2-142}$$

The coefficient of $\{u_x\}$ in (2-142) is defined as the matrix $[HP]$ corresponding to the aerodynamic extra points

$$[HP] = [m_r]^{-1}[D^T M_{ll} + M_{rl}][K_{ll}^a]^{-1}([M_{ll}D + M_{lr}][TR]^T[TRX] + [K_{lx}^a])$$

The second term in (2-142) is defined as the matrix $[HP0]$ corresponding to the user inputs of $\{w_j^g\}$ and $\left\{f_j^e/\bar{q}\right\}$.

$$[HP0] = -[m_r]^{-1}[D^T M_{ll} + M_{rl}][K_{ll}^a]^{-1}\{P_l\}$$

The columns of deflections in $[HP]$ are used to find the mean axis rotations for each aerodynamic extra point, α_{m_i} in the longitudinal case, β_{m_i} in the lateral case, and γ_{m_i} in the directional case, for the user inputs; $[HP0]$ is used in like manner to find the longitudinal mean axis rotation α_{m_0}.

The general problem of obtaining the mean axis rotations with multiple SUPORT points is a problem in solid analytical geometry that is beyond the scope of this guide, but is also not regarded as a practical situation. If there is only a clamped SUPORT at one point (see Figure 2-5) the deflections in $[HP]$ and $[HP0]$ are not needed; only the rotations are of interest, and these are illustrated in the examples of Static Aeroelastic Analysis Problems. In the more general longitudinal case of two SUPORTed grid points (see Figure 2-6) the longitudinal mean axis rotations α_{m_i} and α_{m_0} are found by dividing the difference between the upstream and downstream deflections by the distance between the two grid points. Note that “upstream” and “downstream” must be determined by PARAM,USETPRT,11 in the Bulk Data to account for any resequencing of grid points in the MSC Nastran solution.

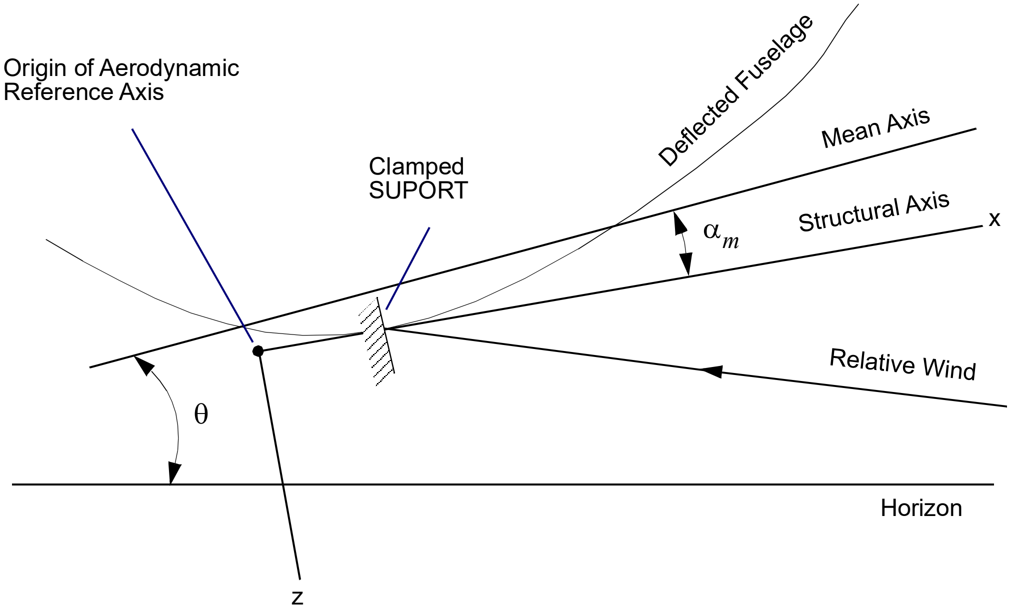


Figure 2-5 Geometry of Deformed Flight Vehicle with Clamped SUPORT

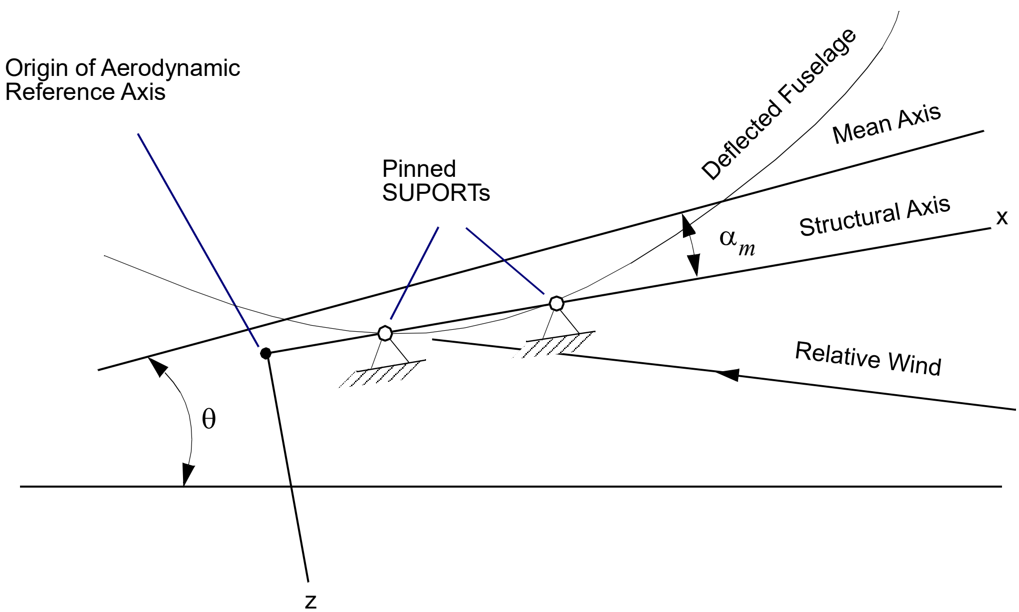


Figure 2-6 Geometry of Deformed Flight Vehicle with Multiple SUPORTs

Speed Derivatives

MSC Nastran assumes a constant forward velocity in all of its aeroelastic solutions and has no capability to estimate induced drag coefficients. However, certain speed derivatives that are required in longitudinal maneuvering studies of aircraft can be obtained using MSC Nastran. The lift and moment aeroelastic coefficients are functions of two speed parameters: Mach number and dynamic pressure, so the expression for the speed derivative is

$$C_v = \frac{\partial C}{\partial(v/V)} = V\frac{\partial C}{\partial m} + 2\bar{q}\frac{\partial C}{\partial \bar{q}}$$

The numerical evaluation of the derivative; for example, with respect to Mach number, is done with the finite difference

$$\frac{\partial C}{\partial m} = \frac{C(m+\Delta m, \bar{q}) - C(m, \bar{q})}{\Delta m}$$

In the calculation of the finite difference derivatives, the perturbations, for example, Δm, must be large enough that the close differences do not lose significance. The above example of the finite difference derivative is a forward difference; a central difference formula might also be used using perturbations on either side of the flight condition. Three MSC Nastran subcases are required to evaluate the speed derivatives by the forward difference equation:

- at the flight condition of m and $\bar{q}$
- with a perturbed Mach number $m + \Delta m$ and $\bar{q}$
- with the flight Mach number m and a perturbed dynamic pressure $\bar{q} + \Delta\bar{q}$

Divergence Analysis

The divergence speeds of a restrained aircraft component may be obtained by solving an eigenvalue problem. The divergence eigenvalue problem for the restrained vehicle can be extracted from the (1,1) partition of (2-114) above:

$$[K_{ll}^a]\{u_l\} = 0 \tag{2-143}$$

Since $[K_{ll}^a] = [K_{ll}] - \bar{q}[Q_{ll}]$, the divergence eigenvalue problem becomes (2-144)

$$[K_{ll} - \lambda Q_{ll}]\{u_l\} = 0 \tag{2-145}$$

where the eigenvalues $\lambda = \bar{q}_d$ are the dynamic pressures for divergence. Only positive values of $\bar{q}_d$ have any physical significance and the lowest value of $\bar{q}_d$ is the critical divergence dynamic pressure.

Flutter Solution Techniques

Flutter is the dynamic aeroelastic stability problem. It can be solved in any speed regime simply by selecting the appropriate aerodynamic theory. In the linear case assumed throughout this guide, the solution involves a series of complex eigenvalue solutions; the eigenvalue problem to be solved depends on the way in which the aerodynamic loads are included in the equations of motion or whether certain damping terms are included.

The manner in which the aerodynamic loads are included depends on how the dimensionless oscillatory aerodynamic coefficients are defined. When Theodorsen (1935) [Reference 58] first developed the American method (K-method) of flutter analysis, he introduced the aerodynamics into a vibration analysis as complex inertial terms and the flutter analysis became a vibration analysis requiring complex arithmetic. At the same time, he introduced an artificial complex structural damping, proportional to the stiffness, to sustain the assumed harmonic motion. Flutter analysis is then a double eigenvalue problem in frequency and velocity, and an iterative solution, using the reduced frequency of the assumed harmonic motion as the iteration parameter, leads to the neutrally stable conditions (flutter frequencies and velocities) at which no artificial damping is required. The artificial damping is therefore seen not to be physically meaningful, other than, perhaps, at speeds near flutter speeds.

At about the same time, Frazer and Duncan (1928) [Reference 16] in England were attempting to solve the flutter problem using aerodynamic stability derivatives in the tradition of Bryan (1911) [Reference 9] who had studied the flight mechanics of rigid aircraft. This approach introduced the aerodynamic loads into the equations of motion as frequency dependent stiffness and damping terms. In this representation it should be noted that the aerodynamic terms are slowly varying functions of the reduced frequency, in contrast to the representation of the aerodynamics in the K-method as mass terms that are highly dependent on the reduced frequency. In what has become known as the "British" method of flutter analysis some iteration is still necessary to "line-up" the eigenvalue solution for frequency with the reduced frequency in each mode. A description of the British method and a comparison with the American method has been given by Lawrence and Jackson (1970) [Reference 32]. A variation of the British method in which the aerodynamic loads are treated as complex springs has been developed by Hassig (1971) [Reference 26]. Hassig called his method the p-k method, and MSC Nastran has adopted his terminology, although it is now applied to the British method. The MSC Nastran terminology is K-method for the American method, and PK-method for the British method. MSC Nastran also has a very efficient K-method, called the KE-method, which does not provide eigenvectors and has no provisions for viscous damping type terms, such as arise in an automatic control system in the equations of motion. Variations on the PK method include the PKS method which solves for the complex eigenvalues by sweeping through a range of k values and extracting solutions without iteration and the PKNL method which can be used to solve flutter equation at matched points (Mach/Velocity/Density) in the atmosphere. Finally, the PKNLS method performs the sweep with matched analysis points.

Generalized Aerodynamic Matrices

(2-4) defines an aerodynamic influence coefficient matrix Q_{kk} that is computed based on the aerodynamic model. For this matrix to be useful in a flutter analysis, two transformations have to take place:

1. The matrices have to be applied to the structural model using the spline techniques discussed in Aeroelastic Modeling.

2. A modal reduction has to be applied to obtain the matrices in generalized form.

Mathematically, those transformations can be expressed as

$$[Q_{ii}] = [\phi_{ai}]^T [G_{ka}]^T [WTFACT][Q_{kk}][G_{ka}][\phi_{ai}] \tag{2-146}$$

where:

Q_{ii}	=	the generalized aerodynamic matrix
ϕ_{ai}	=	a matrix of i-set normal mode vectors in the physical a-set
G_{ka}	=	the spline matrix of (2-22) reduced to the a-set
$WTFACT$	=	the same weighting matrix as W_{kk} defined following (2-21)

A level of complexity is added if the flutter analysis includes the use of extra points. Extra points are used for the representation of control systems and are therefore required in aeroservoelastic analyses. If the extra point deflections result in displacements of the aerodynamic model, the user is required to provide the downwash information explicitly on two DMI entries:

$$\{w_j\} = [D1JE + ik\ D2JE]\{u_e\} \tag{2-147}$$

where $[u_e]$ is a vector of extra point displacements, $D1JE$ and $D2JE$ are the required matrices, and w_j is the resulting downwash.

Generalized aerodynamics for these extra points can be computed as

$$[Q_{ie}] = [\phi_{ai}]^T [G_{ka}]^T [WTFACT][Q_{ke}] \tag{2-148}$$

where, similar to (2-4),

$$[Q_{ke}] = [WTFACT][S_{kj}][A_{jj}]^{-1}[D1JE + ikD2JE] \tag{2-149}$$

The flutter analysis then uses a merged matrix:

$$[Q_{hh}] = \begin{bmatrix} Q_{ii} & Q_{ie} \\ 0 & 0 \end{bmatrix} \tag{2-150}$$

where the h-set is a combination of the i-set normal modes and the e-set extra points. It is seen that the lower e-set rows in the matrix are null. Physically, this indicates that the normal mode deflections do not produce aerodynamic forces on the extra points $(Q_{ei} = 0)$ and that the extra point deflections do not produce aerodynamic loads on the extra points $(Q_{ee} = 0)$.

Interpolation of Q_{hh}

In a typical flutter analysis, the computation of the aerodynamic matrices and the subsequent processing of these matrices to generate the generalized aerodynamic matrices of the previous subsection represents a significant portion of the computer resources required to perform the analysis. These matrices are generated for discrete values of Mach number and reduced frequency. As detailed in the flutter algorithm discussions to follow, the actual flutter analysis is likely to be performed at reduced frequencies (and sometimes Mach numbers) other than one of the available values. These intermediate values are obtained from an interpolation of the available values, and four separate interpolation schemes have been implemented in MSC Nastran. The first two are available for the K- and KE-flutter methods and are special applications of the linear and surface spline. The third is used with the PK-flutter method and is a linear spline method that has been further tailored to aerodynamic applications. For the purpose of this discussion, the four methods are designated (1) linear spline, (2) surface spline, (3) special linear spline and (4) cubic spline.

Linear Spline

The linear spline of Interconnection of the Structure with Aerodynamics is applied to the aerodynamic interpolation task with the spline axis representing reduced frequency values. The torsion terms are ignored in this case, as are the options of attaching springs. Under these circumstances, the interpolation can be written as:

$$Q_{hh}(k_{INT}) = \sum_{j=1}^{nhdpts} C_j Q_{hh}(k_j) \tag{2-151}$$

where C_j is determined from

$$\{C\} = [A]^{-1}\{B\} \tag{2-152}$$

and $[A]$ is a symmetric $nhdpts + 2$ matrix with

$$A_{ij} = \begin{cases} \dfrac{|k_i - k_j|^3}{12} & \text{for } i \text{ and } j \le nhdpts \\ k_i & \text{for } i = nhdpts + 1,\, j \le nhdpts \\ 0 & \text{for } j \ge nhdpts + 1,\, i \ge nhdpts + 1 \end{cases} \tag{2-153}$$

$$B_i = \begin{cases} |k_i - k_{INT}|^3 & \text{for } i \le nhdpts \\ 1 & \text{for } i = nhdpts + 1 \\ k_{INT} & \text{for } i = nhdpts + 2 \end{cases} \tag{2-154}$$

Note that only the first $nhdpts$ rows of the C vector are required in performing the interpolation.

Surface Spline

The surface spline of can be applied in the aerodynamic interpolation task with reduced frequencies and Mach numbers taking the place of the x- and y-coordinates for this application. Again, a number of simplifications can be made for this application, allowing for a terse description of the interpolation algorithm. (2-151) and (2-152) can still be used to represent the interpolation, A is now a symmetric $nhdpts + 3$ matrix with:

$$A_{ij} = \begin{cases} r_{ij}^2 \, ln r_{ij}^2 & i \text{ and } j \le nhdpts \\ 1.0 & i = nhdpts + 1, j \le nhdpts \\ m_i & i = nhdpts + 2, j \ge nhdpts \\ k_i & i = nhdpts + 3, j \le nhdpts \\ 0 & i > nhdpts, j \ge nhdpts \end{cases} \tag{2-155}$$

$$B_i = \begin{cases} R_i^2 \, ln R_i^2 & i \le nhdpts \\ 1.0 & i = nhdpts + 1 \\ m_{INT} & i = nhdpts + 2 \\ k_{INT} & i = nhdpts + 3 \end{cases} \tag{2-156}$$

where:

$$r_{ij}^{\,2} = (k_i - \mathrm{k}_j)^2 + (m_i - m_j)^2$$

$$R_i^{\,2} = (k_i - \mathrm{k}_{INT})^2 + (m_i - m_{INT})^2 \tag{2-157}$$

As in the case of the linear spline, only the first $nhdpts$ rows of the C vector [(2-151)] are required to perform the interpolation.

Special Linear Interpolation

The interpolation task can be thought of as a relatively minor task for the K- and KE-methods in that the user defines the hard points and the interpolated points and can be expected to make a reasonable selection. As detailed below, the PK-method computes the reduced frequency values to which aerodynamics are to be interpolated without user intervention. This calls for a more robust interpolation scheme. For the PK-method, the interpolation has the form

$$Q_{hh}(k_{est}) = \sum_{j=1}^{nhdpts} C_j\left[Q_{hh}^R(k_j) + \frac{i}{k_j}Q_{hh}^I(k_j)\right] \tag{2-158}$$

where Q_{hh}^I/k_j is fit rather than Q_{hh}^I directly since the former quantity is a smoother value of k and because it is needed in the formulation of (2-172). Further, this makes the response data symmetric with respect to a reduced frequency of zero and this "boundary condition" can be applied in the interpolation. The C vector of (2-158) is

$$\{C\} = [A]^{-1}\{B\} \tag{2-159}$$

with

$$A_{ij} = \begin{cases} |k_i - k_j|^3 + |k_i + k_j|^3 & \text{for } i \text{ and } j \le nhdpts \\ 0 & \text{for } i = j = nhdpts + 1 \\ 1 & \text{for } i = nhdpts + 1 \text{ or } j = nhdpts + 1 \end{cases} \tag{2-160}$$

$$B_i = \begin{cases} |k_{est} - k_i|^3 + |k_{est} + k_i|^3 & \text{for } i \le nhdpts \\ 1 & \text{for } i = nhdpts + 1 \end{cases} \tag{2-161}$$

where the $k_i = k_j$ and $k_{est} = k_j$ terms result from the symmetry condition.

Cubic Interpolation

All of the interpolation methods discussed above use all the available discrete k values when performing the interpolation. This sometimes introduces numerical conditioning problems when the interpolation is performed using many discrete values over a wide range. As an alternative, the PK method can invoke a cubic interpolation method that is based on the up to three discrete k values that are closest to the estimated k value required in the computation. The interpolation is performed using:

$$Q_{ij}(k_{est}) = Q_{ij}(k_0) + ((C^3 \cdot \Delta k + C^2) \cdot \Delta k + C^1) \cdot \Delta k$$

Where

k_0	=	the largest discrete k value that is < k_{est}
Δk	=	k_{est} - k_0
$C^{1,\,2,\,3}$	=	Interpolation coefficients determined using a cubic spline (1,2,3 are superscripts, not exponents)

Note that unlike the other interpolation methods, the Cubic method is applied on a term by term basis. If there is only one discrete k value, no interpolation is performed. If the k_{est} value falls outside the range of discrete k's, no extrapolation is performed. Instead, the aerodynamics at the lowest k value is used when k_{est} is lower any discrete k and the aerodynamics at the highest k value are used when k_{est} is higher than any discrete k.

The K-Method of Flutter Solution

The basic equation for modal flutter analysis by the K-method is

$$\left[-M_{hh}\omega^2 + iB_{hh}\omega + (1+ig)K_{hh} - \left(\frac{1}{2}\rho V^2\right)Q_{hh}(m,k)\right]\{u_h\} = 0 \tag{2-162}$$

where:

M_{hh}	=	modal mass matrix, usually (but not necessarily) diagonal
B_{hh}	=	modal damping matrix

K_{hh}	=	modal stiffness matrix, usually (but not necessarily) diagonal; may be complex (with actual structural damping); will be singular if there are rigid body modes
m	=	Mach number
k	=	reduced frequency = $\omega\bar{c}/(2V)$
$\bar{c}$	=	reference length
$Q_{hh}(m,k)$	=	aerodynamic force matrix, which is a function of parameters m and k
ω	=	circular frequency = $2\pi f$
g	=	artificial structural damping
ρ	=	fluid density
V	=	velocity
u_h	=	modal amplitude vector, sometimes called modal participation factors

Note that k, V, and ω are not independent.

For the K-method of solution, the aerodynamic term is converted to an equivalent aerodynamic mass

$$\left[-\left[M_{hh}+\frac{\rho}{2}\left(\frac{\bar{c}}{2k}\right)^2 Q_{hh}(m,k)\right]\frac{\omega^2}{1+ig}+B_{hh}\frac{i\omega}{\sqrt{1+ig}}+K_{hh}\right]\{u_h\} = 0 \tag{2-163}$$

The term involving B_{hh} in (2-163) has been multiplied by $\sqrt{1+ig}$ for mathematical convenience, and is valid only at flutter, that is, when $g = 0$. (2-163) is solved as an eigenvalue problem for a series of values for parameters m, k, and ρ. The complex eigenvalue is $\omega^2/(1+ig)$, which can be interpreted as real values of ω and g. The velocity, V, is recovered from $V = \omega\bar{c}/2k$. Flutter occurs for values of m, k, and ρ for which $g = 0$. The solutions are not valid except when $g = 0$, since the aerodynamic force terms are valid only for sinusoidal motion and g is not a physical damping. A slight variation has been used with MSC Nastran. The equation is written as

$$\left[\left[\left(\frac{2k}{\bar{c}}\right)^2 M_{hh}+\frac{\rho}{2}Q_{hh}(m,k)\right]\left(\frac{-V^2}{1+ig}\right)+\left(\frac{2k}{\bar{c}}\right)B_{hh}\frac{iV}{\sqrt{1+ig}}+K_{hh}\right]\{u_h\} = 0 \tag{2-164}$$

Thus, the square of the new eigenvalues is

$$p^2 = \left(\frac{-V^2}{(1+ig)}\right) \quad (2\text{-}165)$$

Where $p = p_r + p_i$ and $p^2 = p_r\, p_r - p_i\, p_i - 2\, p_r\, p_i\, i$ *(These are inserted equations 2.122 and 2.123)*

(2-165) may be written as

$$p^2 = V^2 \frac{(1-ig)}{1+g^2} = a + ib \quad (2\text{-}166)$$

so that

$$g = -b/a \quad (2\text{-}167)$$

$$V = \sqrt{-\frac{(a^2+b^2)}{a}} \quad (2\text{-}168)$$

$$f = \frac{kV}{\pi\bar{c}} \quad (2\text{-}169)$$

The eigenvalues problem is expressed in a quadratic form in (2-155). The manner of solution depends on which of the various complex eigenvalues methods available in MSC Nastran is selected by the user. For more information on the theory of complex eigenvalues analysis, see the *MSC Nastran Numerical Methods User's Guide* (Komzsik, 1993, Section 7.1 [Reference 33]).

The K-method of flutter analysis is a looping procedure. The values of V, g, and $f = \omega/2\pi$ are solved for various values of m, k, and ρ. Plots of V versus g can be used to determine the flutter speed(s) (where g goes through zero to positive values).

The KE-method of Flutter Solution

A more efficient K-method of flutter analysis is possible if the analyst is willing to neglect viscous dampings from all sources, for example, from the structure or a control system, and to restrict the solution to eigenvalues and not require eigenvectors. The equation to be solved becomes (2-164) with the term containing B_{hh} deleted; note that complex structural damping may still be included in K_{hh}. Many of the operations can then be done in-core with a consequent increase in efficiency. This efficient K-method algorithm is called the KE-method. With this increase in efficiency, a greater number of points on a flutter stability curve can be obtained for a given cost, and cases with poorly behaved stability curves can be studied more thoroughly. This method gives results similar to those of Desmarais and Bennett (1974) [Reference 12].

In order to sort the roots so that curves can be drawn, the roots must be ordered. For the first value of k, the roots are accepted in the order output by the upper Hessenberg eigenvalue subroutine. If we denote the i-th eigenvalue for the n-th reduced frequency k_n by $p_{i,n}$, we may define an extrapolated eigenvalue as

$$p_{i,n}^{(e)} = p_{i,n-1} + (k_n - k_{n-1})(p_{i,n-1} - p_{i,n-2})/(k_{n-1} - k_{n-2}),$$
$$n = 2, 3, 4, \ldots \quad (2\text{-}170)$$

in which $p_{i,0}$ is chosen equal to $p_{i,1}$. Then the values of $p_{i,n}$ are ordered according to closeness to $p_{i,n}^{(e)}$ where the "closeness" is measured by a minimum value of

$$[\mathrm{Re}(p_{i,n}^{(e)} - p_{i,n})]^2 + [\mathrm{Im}(p_{i,n}^{(e)} - p_{i,n})]^2 \quad (2\text{-}171)$$

With this sorting, the *V-g* and *V-f* curves produced using the MSC Nastran NASPLOT utility can be interpreted physically. The curves from the K-method, on the other hand, are extremely difficult to interpret.

The PK-Methods of Flutter Solution

The fundamental equation for modal flutter analysis by the PK-method is

$$\left[M_{hh}p^2 + \left(B_{hh} - \frac{1}{4}\rho\bar{c}VQ_{hh}^I/k\right)p + \left(k_{hh} - \frac{1}{2}\rho V^2 Q_{hh}^R\right)\right]\{u_h\} = 0 \quad (2\text{-}172)$$

where the new terms are:

Q_{hh}^I	=	modal aerodynamic damping matrix, a function of Mach number, m, and reduced frequency, k
Q_{hh}^R	=	modal aerodynamic stiffness matrix, a function of Mach number, m, and reduced frequency, k
p	=	eigenvalue = $\omega(\gamma \pm i)$
γ	=	transient decay rate coefficient (Note that the structural damping coefficient $g = 2\gamma$)

The matrix terms in (2-172) are all real. Q_{hh}^R and Q_{hh}^I are, respectively, the real and imaginary parts of $Q_{hh}(m,k)$. Note that the circular frequency and the reduced frequency are not independent since $k = \omega\bar{c}/2V$, and furthermore, that

$$k = (\bar{c}/2V)\mathrm{Im}(p) \quad (2\text{-}173)$$

For the PK-methods of solution, (2-172) is rewritten in the state-space form with twice the order.

$$[A - pI]\{\bar{u}_h\} = 0 \tag{2-174}$$

where $[A]$ is the real matrix

$$[A] = \left[\begin{array}{c|c} 0 & I \\ \hline -M_{hh}^{-1}\left[K_{hh} - \frac{1}{2}\rho V^2 Q_{hh}^R\right] & -M_{hh}^{-1}\left[B_{hh} - \frac{1}{4}\rho \bar{c} V Q_{hh}^I / k\right] \end{array}\right] \tag{2-175}$$

and $\{\bar{u}_h\}$ now includes both modal displacements and velocities. The eigenvalues of the real matrix $[A]$] are either real or complex conjugate pairs. Real roots indicate a convergence or divergence as in the cases of the roll subsidence (rigid body) mode or a structural (torsional) divergence mode. For the real roots, the damping is expressed as the decay rate coefficient, which is the distance travelled (measured in chord lengths) to half (or double) amplitude.

$$\begin{aligned} g &= 2\gamma \\ &= \frac{2p\bar{c}}{(ln2)V} \end{aligned} \tag{2-176}$$

However, the majority of the eigenvalues will be complex conjugate pairs.

The order of calculations for different values of density, velocity and/or Mach number is indicated in Flutter Analysis, 134.

The principal advantage of the PK-methods is that they produce results directly for given values of velocity, whereas the K- and KE-methods require iteration to determine the reduced frequency of flutter. In addition, the damping given by $2\gamma_{ss}^{(c)}$ found from (2-180) is a more realistic estimate of the physical damping than the parameter g in (2-176), which is a mathematical artifice.

MSC Nastran distinguishes among four different PK-methods:

1. The PK method uses an iterative technique to solve for all combinations of user input densities, Mach numbers and velocities (rho,M,V).
2. The PKNL method uses the same iterative technique as the PK method, but now only at order sets of (rho, M, V); that is, the first density, Mach and velocity followed by the second density, Mach and velocity and so on.
3. The PKS method, which performs a sweep through a range of k values and selects flutter roots as the estimated k-value and the extracted value line up (see below). All combinations of (rho, M,V) are analyzed.
4. the PKNLS method is the same as PKS with no looping across all combinations.

The PK and PKNL solutions of (2-172) require an iterative solution so that (2-173) is satisfied along with (2-172). The iterations begin with $k = 0$. The roll subsidence root or the static structural divergence roots are obtained for $k = 0$ The oscillatory rigid body (that is, short-period or Dutch-roll) roots and oscillatory roots are found from the following algorithm. The algorithm is based on a desire to determine stability at a given speed independently of the stability at lower or higher speeds and the fact that the aerodynamic terms in (2-172) are slowly varying functions of the reduced frequency.

The iteration begins at $k = 0$ [Q_{hh}^R and Q_{hh}^I/k are extrapolated to $k = 0$ from the available values of $Q_{hh}(m,k)$]. All real roots immediately satisfy (2-173) but the complex roots do not. The iteration for the complex roots then proceeds as follows. In general, let the complex pairs of eigenvalues be written as

$$p_{rs}^{(j)} = \omega_{rs}^{(j)}(\gamma_{rs}^{(j)} \pm i) \tag{2-177}$$

where r denotes the oscillatory mode number ordered by frequency $(\omega_{1s} < \omega_{2s} < \ldots)$, s denotes the number of the oscillatory mode under investigation, and j denotes the iteration (eigenvalue solution) number so that the next estimate of the (nonzero) reduced frequency is

$$k_s^{(j)} = \omega_{ss}^{(j)}\left(\frac{\bar{c}}{2V}\right)$$

To find the first oscillatory root the estimate of the first nonzero reduced frequency is taken as

$$k_1^{(0)} = \omega_{11}\left(\frac{\bar{c}}{2V}\right) \tag{2-178}$$

Convergence to the first oscillatory root then occurs when

$$\left|k_1^{(j)} - k_1^{(j-1)}\right| \begin{array}{l} < \varepsilon \text{ for } k_1^{(j-1)} < 1.0 \\ < \varepsilon k_1^{(j-1)} \text{ for } k_1^{(j-1)} \geq 1.0 \end{array} \tag{2-179}$$

where ε is a user input with a default value of 0.001. Let the converged complex eigenvalues be

$$p_{rs}^{(c)} = \omega_{rs}^{(c)}(\gamma_{rs}^{(c)} \pm i) \tag{2-180}$$

where only $p_{ss}^{(c)}$ satisfies both (2-173) and (2-175). Then the search for the next oscillatory mode begins by increasing s by one, and the first estimate of the next reduced frequency is

$$k_s^{(0)} = \omega_{s,\,s-1}^{(c)}\left(\frac{\bar{c}}{2V}\right) \tag{2-181}$$

The iteration of (2-177) and (2-178) continues until

$$\left|k_s^{(j)} - k_s^{(j-i)}\right| < \varepsilon \text{ for } k_s^{(j-1)} < 1.0\text{, or } < \varepsilon k_s^{(j-1)} \text{ for } k_s^{(j-1)} \geq 1.0 \qquad (2\text{-}182)$$

is satisfied. (2-180) and (2-181) begin the search for each of the higher modes of interest.

The PKS and PKNLS solutions

The iterative PK or PKNL processes of the previous paragraph sometimes encounter a flutter analysis task that cannot be solved completely so that only a limited set of results are obtained. When this occurs, a message is printed:

```
**** (USER WARNING MESSAGE 4581 (FA1PKE)

PK FLUTTER ANALYSIS FAILED TO CONVERGE FOR LOOP xx, ROOT yy
```

Figure 2-7 shows a comparison of extracted and estimated reduced frequency values and shows how the iterative scheme can break down. It is seen that most of the estimated roots line up in straight lines that are almost invariant with respect to the estimated frequency. However, one root starts at a kext of 3.0 and falls rapidly to kext =0.0, crossing the 45 degree line near kext=l.O. It is this root that gives the PK algorithm trouble since its order changes as kest increases, violating an assumption of the algorithm.

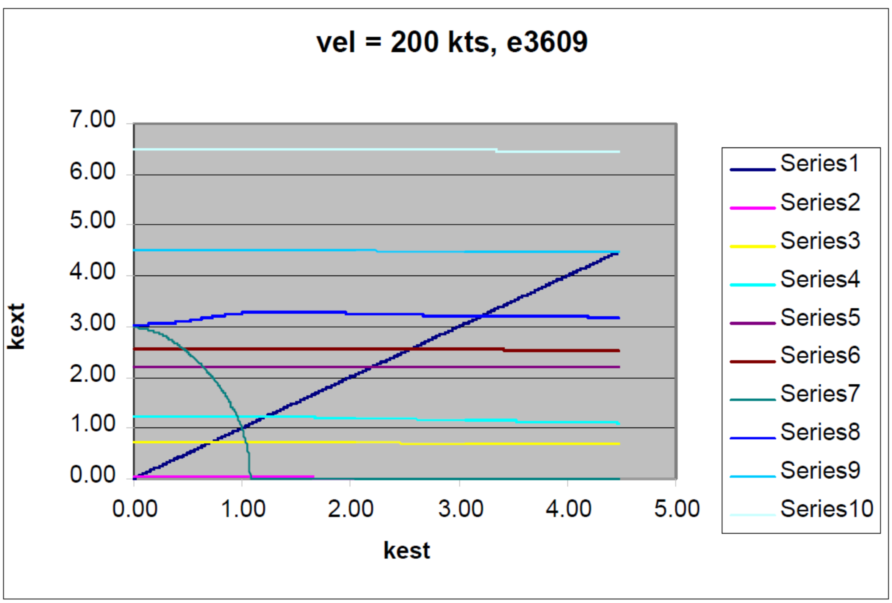


Figure 2-7 Reduced Frequency Sweep for A Test Deck Results in a Failure to Converge Message with the PK Method.

The PKS (or PKNLS) method simply sweeps across the k-range with a series of complex eige~alyses at each of the estimate~ k-values. A determination is made as to when the 45 degree line is crossed and the corresponding flutter root is stored.

In this way, the FAILURE TO CONVERGE message is no longer issued, while the other benefits of the PK method (ability to deal with real roots, better estimate of complex roots, and use in optimization) are retained.

The sweep occurs at equally spaced reduced frequency intervals ranging from 0.0 through $k = \pi c_{ref}$ OMAX / Velocity where c_{ref} is the reference chord and OMAX is the maximum frequency for the sweep in Hz. The default for OMAX is the maximum extracted normal modes frequency. The number of steps in the sweep (NINT) is determined from NINT = INT(1.0/EPS) with a default value of 1000.

Dynamic Aeroelastic Analysis

Dynamic aeroelasticity differs from the flutter analysis of the previous section in that the right-hand side of (2-162) is no longer zero. Instead, loading, which can be in either the frequency or the time domain, is applied. For both types of loading, MSC Nastran performs the primary analyses in the frequency domain. If the user has supplied loadings in the time domain, Fourier Transform techniques are used to convert the loadings into the frequency domain, a frequency response analysis is performed and the computed quantities are transformed back to the time domain using Inverse Fourier Transform techniques. This section first describes the frequency response analysis that is the basis of all MSC Nastran dynamic aeroelastic analysis and then discusses the special topics of transient response analysis and random response analysis.

Aeroelastic Frequency Response Analysis

Aeroelastic frequency response analysis in MSC Nastran is performed in modal coordinates and has a basic equation of the form

$$\left[-M_{hh}\omega^2 + iB_{hh}\omega + (1+ig)K_{hh} - \frac{1}{2}\rho V^2 Q_{hh}(m,k)\right]\{u_h\} = \{P(\omega)\} \tag{2-183}$$

where all terms on the left-hand side are identical to those of (2-162) and are defined with that equation. The right-hand side provides the loading in modal coordinates, which can be aerodynamic or nonaerodynamic in nature and is a function of the analysis frequency. Nonaerodynamic generalized loads, designated , are obtained in the standard fashion from the loadings applied to physical coordinates [compare with Eq. (5-11) in the *MSC Nastran Dynamic Analysis User's Guide*] and do not require further comment here. The aeroelastic (gust) portion of the loading does require further comment that is similar in nature to the discussion of the generalized aerodynamic matrices of the previous subsection.

A prerequisite to performing aerodynamic gust analysis is the availability of an aerodynamic matrix that provides the forces on the aerodynamic elements due to an applied downwash at any other element:

$$[Q_{kj}] = [S_{kj}][A_{jj}]$$

which can be transformed to modal coordinates using:

$$[Q_{ij}] = [\phi_{ia}][G_{ka}]^T[WTFACT][Q_{kj}]$$

Since extra points cannot affect the gust loading, there are no generalized loadings associated with them so that matrix Q_{hj} (which provides the generalized loadings in the modal set) is obtained by adding a null matrix onto the bottom of Q_{ij} .

The Q_{hj} matrix supplies the generalized aerodynamic forces due to the downwash vector at the collocation points. For the matrix to be useful in the gust analysis, two other steps are required. First, the Q_{hj} and Q_{hh} matrices must be interpolated to all the frequencies required in the analysis from the discrete reduced frequencies at which the aerodynamics have been calculated. This is done using the Specialized Linear Interpolation technique of the previous subsection applied to the two matrices. The other step is the generation of the gust downwash matrix. This is a function of frequency and the geometry of the aerodynamic model:

$$w_j(\omega_i) = cos\gamma_j e^{-i\omega_i(x_j - x_o)/V} \tag{2-184}$$

where:

ω_i	=	excitation frequency
γ_j	=	dihedral angle of the j-th aerodynamic element
x_j	=	x-location of the j-th aerodynamic element in the aerodynamic coordinate system
x_o	=	user-supplied offset distance for the gust

It is seen that this represents a one-dimensional gust field, that is, the gust varies only in its x-coordinate. The generalized load due to the aerodynamic gust is then

$$\{PHF_2(\omega)\} = \bar{q}w_g PP(\omega)[Q_{hj}]\{w_j(\omega)\} \tag{2-185}$$

where:

$\bar{q}$	=	dynamic pressure
w_g	=	gust scale factor
PP	=	user-supplied frequency variation of the gust. (This may also be obtained from a Fourier transform of the user-supplied discrete gust.)

and the total frequency dependent loading applied in (2-183) is

$$\{P(\omega)\} = \{PHF_2(\omega)\} + \{PHF(\omega)\} \tag{2-186}$$

The solution of (2-183) entails solving for the generalized displacements by decomposition/forward-backward substitution techniques applied to the coupled set of complex equations. Because modal reduction techniques have been applied, the solution costs are typically modest. Once the generalized displacements have been computed, standard data recovery techniques can be used to determine physical displacements, velocities, stress, etc.

Aeroelastic Transient Response Analysis

As discussed in the introduction to this section, Aeroelastic Transient Analysis relies on Fourier transform techniques. Transient analysis by a Fourier transformation is separated into three phases. First, the loads (defined as a function of time) are transformed into the frequency domain. Second, the responses are computed in the frequency domain using the algorithm of the preceding subsection. Third, these responses (in the frequency domain) are transformed back to the time domain.

Two forms of the transform are considered, the Fourier series and the Fourier integral, which are defined using the following terminology.

stable. Using the Fourier method, the pulse is replaced by a series of pulses with period $1/(\Delta f)$. As can be seen, this gives an accurate representation if the system is very stable, but an incorrect impression if the system is only slightly stable. Guidelines that lead to valid results using the Fourier method include:

1. The system should be stable.
2. The forcing functions should be zero for some time interval to allow decay.
3. The frequency interval $\Delta f \leq 1/(T_{pulse} + T_{decay})$

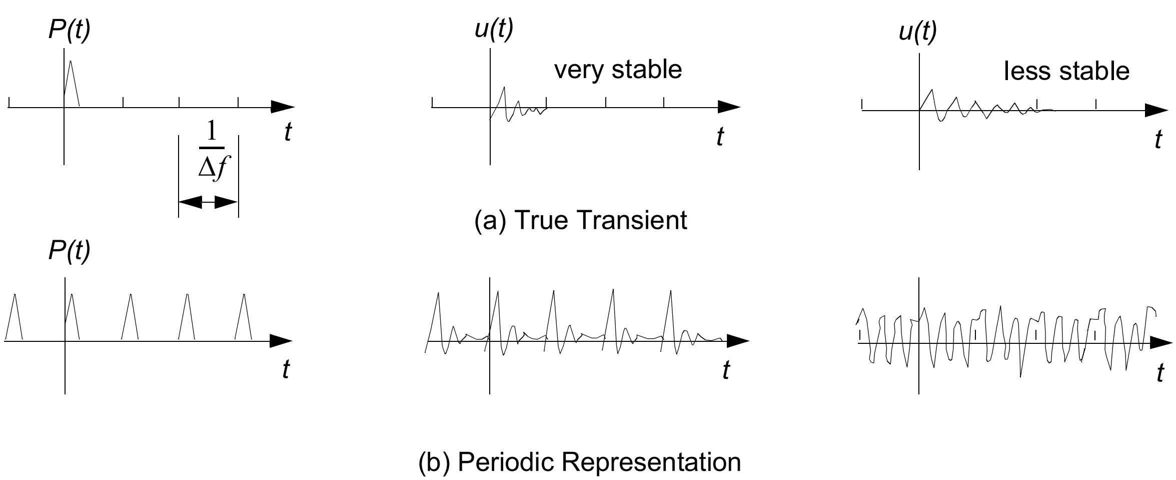


Figure 2-8 Response of a Damped Oscillator to a Triangular Pulse

If the system has unstable modes, these will appear as a precursor before the pulse, just like a "stable mode in reverse time."

The use of both equal frequency intervals and unequal intervals has been studied briefly and results are shown by Rodden, Harder, and Bellinger (1979) [Reference 50] for a lightly damped, single degree-of-freedom oscillator. It has been found there that the combination of a few well-chosen values near the resonant frequencies and a uniformly spaced set of frequencies elsewhere produces reasonable results for the lightly damped example considered. However, further convergence studies on more general examples are needed.

Random Response Analysis

The major loads to which an aerospace vehicle is subjected can be predicted for the most part from its design mission and maneuvering requirements. However, the total environment cannot be predicted exactly and statistical methods based on the theory of random processes must be employed to complete the description. Examples of random processes in aeroelasticity include response to atmospheric gusts and to aerodynamic buffeting. The random process theory considered in MSC Nastran is based on generalized harmonic analysis, that is, frequency response techniques, and assumes that the system is linear and that both the excitation and response are stationary with respect to time.

A fundamental quantity in random analysis theory is the autocorrelation, $R_j(\tau)$, of a physical variable, u_j, which is defined by

$$R_j(\tau) = \lim_{T \to \infty} \frac{1}{T} \int_0^T u_j(t) u_j(t-\tau) dt \tag{2-187}$$

Note that $R_j(0)$ is the time average value of u_j^2, which is an important quantity in the analysis of structural fatigue failure. The power spectral density $S_j(\omega)$ of u_j is defined by

$$S_j(\omega) = \lim_{T \to \infty} \frac{2}{T} \left| \int_0^T e^{-i\omega t} u_j(t) dt \right|^2 \tag{2-188}$$

It may be shown (using the theory of Fourier integrals) that the autocorrelation function and the power spectral density are Fourier transforms of each other. Thus

$$R_j(\tau) = \frac{1}{2\pi} \int_0^\infty S_j(\omega) cos(\omega\tau) d\omega \tag{2-189}$$

from which the mean-square theorem follows

$$\bar{u}_j^2 = R_j(0) = \frac{1}{2\pi} \int_0^\infty S_j(\omega) d\omega \tag{2-190}$$

Note: The factor $1/(2\pi)$ in (2-189) is omitted by some authors, or is sometimes replaced by other factors. The value of the factor depends on the definition of $S_j(\omega)$ (2-188).

The expected value of the number of zero crossings with positive slope per unit time, or *mean frequency*, is another quantity of interest for fatigue analysis and design of aircraft for gusts. This mean frequency, N_0, can be found from the power spectral density:

$$N_0^{\ 2} = \frac{\int_0^\infty (\omega/2\pi)^2 S_j(\omega) d\omega}{\int_0^\infty S_j(\omega) d\omega} \tag{2-191}$$

The mean frequency, N_0, is thus the root mean square frequency, in which the power spectral density is used as a weighting function.

The transfer function theorem [see, for example, Bisplinghoff, Ashley, and Halfman (1955, App. C) [Reference 8]] states that if $H_{ja}(\omega)$ is the frequency response of any physical variable, u_j, due to some excitation source, $Q_a(t)$, (for example, a point force, or a distributed loading condition), so that if

$$u_j(\omega) = H_{ja}(\omega) Q_a(\omega) \tag{2-192}$$

where $u_j(\omega)$ and $Q_a(\omega)$ are the Fourier transforms of $u_j(t)$ and $Q_a(t)$, then the power spectral density of the response, $S_j(\omega)$, is related to the power spectral density of the source, $S_a(\omega)$, by

$$S_j(\omega) = |H_{ja}(\omega)|^2 S_a(\omega) \tag{2-193}$$

(2-193) is an important result because it allows the statistical properties (for example, the autocorrelation function) of the response of a system to random excitation to be evaluated via the techniques of frequency response.

If the cross-correlation function between any pair of sources

$$R_{ab}(\tau) = \lim_{T \to \infty} \frac{1}{T} \int_0^T Q_a(t) Q_b(t-\tau) dt \tag{2-194}$$

is null, the sources are said to be statistically independent and the power spectral density of the total response is equal to the sum of the power spectral densities of the responses due to individual sources. Thus,

$$S_j(\omega) = \sum_a S_{ja}(\omega) = \sum_a |H_{ja}(\omega)|^2 S_a(\omega) \tag{2-195}$$

If the sources are statistically correlated, the degree of correlation can be expressed by a cross-spectral density, S_{ab}, and the spectral density of the response may be evaluated from

$$S_j(\omega) = \sum_a \sum_b H_{ja} H_{jb}^* S_{ab} \tag{2-196}$$

where H_{jb}^* is the complex conjugate of H_{jb}. Note that $[S_{ab}]$ is a Hermitian matrix, that is, $[S_{ab}]^T = S_{ab}^*$. (2-196) can be generalized for multiple responses to

$$[S_{ij}] = [H_{ai}]^T [S_{ab}][H_{bj}^*] \tag{2-197}$$

In applying the theory, it may not be necessary to consider the sources to be forces at individual points. An ensemble of applied forces that is completely correlated (that is, a loading condition) may also be treated as a source. For example, a plane pressure wave from a specified direction may be treated as a source. Furthermore, the response may be any physical variable including internal forces and stresses as well as displacements, velocities, and accelerations.

In MSC Nastran, random response analysis is treated as a data recovery procedure that is applied to the results of a frequency response analysis. The frequency response analysis is performed for loading conditions, $\{P_a\}$, at a sequence of frequencies, ω_i. Normal recovery procedures are applied to the output of the frequency response analysis module [see the *MSC Nastran Handbook for Dynamic Analysis*, Section 4.5.2], resulting in a set of output quantities, u_j.

The calculation of power spectral densities and autocorrelation functions for the output quantities is performed in the random response analysis module. The inputs to the calculation are the frequency responses, $H_{ja}(\omega_i)$, of quantities u_j to loading conditions $\{P_a\}$ at frequencies ω_i and the auto- or cross-spectral densities of the loading conditions, S_a or S_{ab}. The response quantities, u_j may be displacements, velocities, accelerations, internal forces, or stresses. The power spectral densities of the response quantities are calculated by (2-196) or by (2-193), depending on whether the loading conditions are correlated or uncorrelated. At the user's option, the spectral densities due to all sources, assumed independent, may be combined by means of (2-195).

The autocorrelation function is computed by the following approximation to (2-189).

$$R_j(\tau) = \frac{1}{2\pi\tau} \sum_{i=1}^{N-1} \frac{S_j(\omega_{i+1}) - S_j(\omega_i)}{(\omega_{i+1} - \omega_i)\tau} [cos(\omega_{i+1}\tau) - cos(\omega_i\tau)] \tag{2-198}$$

$$+ S_j(\omega_{i+1}) sin(\omega_{i+1}\tau) - S_j(\omega_i) sin(\omega_i\tau)$$

which assumes that $S_j(\omega)$ varies linearly between ω_i and ω_{i+1} and also assumes that $S_j(\omega) = 0$ for $\omega < \omega_1$ and $\omega > \omega_N$. The user specifies the sequence of values of τ. The rms value of the response, $\bar{u}_j$, is evaluated as the square root of a trapezoidal approximation to the integral in (2-190), that is,

$$\bar{u}_j = \left[\frac{1}{4\pi}\sum_{i=1}^{N-1}[S_j(\omega_{i+1}) + S_j(\omega_i)](\omega_{i+1} - \omega_i)\right]^{1/2} \tag{2-199}$$

The mean frequency, N_0, is evaluated from (2-191), using a trapezoidal approximation to the curve for $S_j(\omega)$

$$N_0 = \frac{\bar{r}_j}{\bar{u}_j} \tag{2-200}$$

with

$$\bar{r}_j = \left[\sum_{i=1}^{N-1}(\alpha S_j(\omega_i) + \beta S_j(\omega_{i+1}))(\omega_{i+1} - \omega_i)\right]^{1/2} \tag{2-201}$$

$$\alpha = \frac{3\omega_i^2 + 2\omega_i\omega_{i+1} + \omega_{i+1}^2}{96\pi^3} \tag{2-202}$$

$$\beta = \frac{\omega_i^2 + 2\omega_i\omega_{i+1} + 3\omega_{i+1}^2}{96\pi^3} \tag{2-203}$$

The power spectral densities, S_j, are plotted versus frequency and the autocorrelation functions, $R_j(\tau)$, are plotted versus the time delay, τ, at the user's request. Cross-correlation functions and cross-spectral densities between different output quantities are not calculated.

The measured power spectral density function for atmospheric turbulence has been fitted with analytic functions by several authors. Two of the commonly used functions are those of Dryden and von Karman [see, for example, Taylor (1965, pp. 200-202) [Reference 57]]. They can both be expressed by the equation,

$$S_a(\omega) = \frac{2w_g^2(L/V)[1 + 2(p+1)(kL\omega/V)^2]}{[1 + (kL\omega/V)^2]^{p+3/2}} \tag{2-204}$$

where:

$S_a(\omega)$	=	power spectral density (units of $1/(Hz)$)
w_g	=	RMS gust velocity
ω	=	circular frequency
L	=	scale of turbulence (length units)
V	=	airplane velocity (velocity units)

The values of the parameters k and p are given in the following table:

	Dryden	von Karman
k	1.0	1.339
p	1/2	1/3

A special data entry (TABRNDG) is used to select this analytic form in MSC Nastran. The user supplies w_g, L, and V, and selects either the Dryden or the von Karman parameters.

Aeroelastic Design Sensitivities and Optimization

Design sensitivity analysis is used to compute the rate of change, or first derivative, of a particular response quantity with respect to a change in a given structural parameter, or design variable. In MSC Nastran, these responses may be computed using a number of analysis disciplines: statics, normal modes, buckling, direct and modal frequency response, and modal transient response.

Static Aeroelastic Sensitivity

Static aeroelasticity can be considered a special case of standard static structural analysis with the equilibrium equation

$$[K]\{u\} = \{P\} \tag{2-205}$$

In static aeroelasticity, the stiffness matrix contains inertial terms related to quasi-rigid body accelerations and aerodynamic terms from the structural deformations and from the extra degrees of freedom related to aerodynamic variables. The sensitivity of (2-205) is simply its partial derivative with respect to a design variable x

$$[K]\{\Delta u\} = \{\Delta P\} - [\Delta K]\{u\} \tag{2-206}$$

where Δ is used to denote partial differentiation with respect to the design variable, that is, $\Delta \equiv \partial/\partial x$. This sensitivity calculation can be performed in much the same way as the static sensitivity analysis discussed in the *MSC Nastran Design Sensitivity and Optimization User's Guide*. The details of the static aeroelastic sensitivity follow.

To explain the sensitivity analysis, it is useful to start from the static aeroelastic equations in the g-set

$$\begin{bmatrix} K_{gg} - \bar{q}A_{gg} & -\bar{q}A_{gx} \\ 0 & 0 \end{bmatrix} \begin{Bmatrix} u_g \\ u_x \end{Bmatrix} + \begin{bmatrix} M_{gg} & 0 \\ 0 & 0 \end{bmatrix} \begin{Bmatrix} \ddot{u}_g \\ 0 \end{Bmatrix} = \begin{Bmatrix} P_g \\ 0 \end{Bmatrix} \tag{2-207}$$

The A matrices, which contain the aerodynamics, are not actually formed in the g-set in MSC Nastran but are shown here to initiate the following discussion.

The mean-axis condition that is used in static aeroelasticity [see (2-125)] imposes additional requirements on the sensitivity equation. This orthogonality condition is imposed in the a-set and can be written as

$$\begin{bmatrix} D & I \end{bmatrix}^T \begin{bmatrix} M_{ll} & M_{lr} \\ M_{rl} & M_{rr} \end{bmatrix} \begin{Bmatrix} u_l \\ u_r \end{Bmatrix} = \{0\} \tag{2-208}$$

If (2-205) is reduced to the a-set and coupled with (2-206) the basic equation for static aeroelasticity is obtained [compare with (2-127)].

$$\begin{bmatrix} K^a_{ll} & K^a_{lr} & (M_{ll}D + M_{lr}) & K^a_{lx} \\ (D^T M_{ll} + M_{rl}) & (D^T M_{lr} + M_{rr}) & 0 & 0 \\ (D^T K^a_{ll} + K^a_{rl}) & (D^T K^a_{lr} + K^a_{rr}) & m_r & (D^T K^a_{lx} + K^a_{rx}) \end{bmatrix} \begin{Bmatrix} u_l \\ u_r \\ \ddot{u}_r \\ u_x \end{Bmatrix} \tag{2-209}$$

$$= \begin{Bmatrix} P_l \\ 0 \\ P_r + D^T P_l \end{Bmatrix}$$

The basic sensitivity equation for static aeroelasticity has a similar form

$$\begin{bmatrix} K^a_{ll} & K^a_{lr} & (M_{ll}D + M_{lr}) & K^a_{lx} \\ (D^T M_{ll} + M_{rl}) & (D^T M_{lr} + M_{rr}) & 0 & 0 \\ (D^T K^a_{ll} + K^a_{rl}) & (D^T K^a_{lr} + K^a_{rr}) & m_r & (D^T K^a_{lx} + K^a_{rx}) \end{bmatrix} \begin{Bmatrix} \Delta u_l \\ \Delta u_r \\ \Delta \ddot{u}_r \\ \Delta u_x \end{Bmatrix} = \begin{Bmatrix} DPL_l \\ D^T DML_l + DML_r \\ D^T PL_l + DPL_r \end{Bmatrix} \quad (2\text{-}210)$$

where the PL terms represent the pseudoloads caused by modifications to the structure. For static aeroelasticity, the total perturbed load in the g-set can be developed based on (2-207).

$$\{PL_g\} = \{\Delta P_g\} - [\Delta K_{gg}]\{u_g\} - [\Delta M_{gg}]\{\ddot{u}_g\} \quad (2\text{-}211)$$

The first term on the right-hand size is the sensitivity of the applied loads to the design variables. Gravity and thermal type loadings can be affected by the design variables. Note that aerodynamic terms are not included in the load sensitivity equation since these terms are invariant with respect to the design variables.

The DML term of (2-210) results from the variation of the mean-axis constraint of (2-208). The D matrix of the latter equation in invariant with respect to the structural parameter changes so that the sensitivity is simply

$$\begin{bmatrix} D & I \end{bmatrix}^T \begin{bmatrix} M_{ll} & M_{lr} \\ M_{rl} & M_{rr} \end{bmatrix} \begin{Bmatrix} \Delta u_l \\ \Delta u_r \end{Bmatrix} = -\begin{bmatrix} D & I \end{bmatrix}^T \begin{bmatrix} \Delta M_{ll} & \Delta M_{lr} \\ \Delta M_{rl} & \Delta M_{rr} \end{bmatrix} \begin{Bmatrix} u_l \\ u_r \end{Bmatrix} \equiv \begin{Bmatrix} DML_l \\ DML_r \end{Bmatrix} \quad (2\text{-}212)$$

This equation points to the requirement for a vector of the form

$$[\Delta M_{gg}]\{u_g\} \quad (2\text{-}213)$$

The reduction of the pseudoload to the a-set required for (2-210) follows standard reduction techniques.

A key point is that the matrix on the left-hand side of (2-210) is the same as the left-hand matrix of (2-209) so that operations already performed on this matrix as part of the analysis do not have to be repeated for the sensitivity calculations.

In applying (2-210), there are three types of responses for static aeroelasticity for which sensitivity analysis is supported and the sensitivity calculation varies slightly for each. The first type is for the responses already available from static sensitivity, for example, displacements, forces, and stresses. The sensitivity of these responses is derived based on sensitivities of the elastic deformations. These sensitivities are recovered from the Δu_l and Δu_r terms of (2-210) while using the displacement and accelerations vectors that were computed during the recovery phase of the trim analysis. A simplification results from the consideration that the static aeroelastic solution is performed relative to SUPORTed degrees of freedom so that u_r, and therefore Δu_r, are zero in the sensitivity equation.

The second type of response is for the TRIM variables. The sensitivities of these displacements are obtained directly in (2-210) and as a prerequisite to the first type of response discussed above.

The third type of response is for Stability Derivatives. These derivatives are independent of the trim deformations and therefore require significant special code to accommodate their sensitivity calculation. That is, pseudodisplacements (and accelerations) are required that represent the deflections (and accelerations) that would occur if the aerodynamic extra point associated with the stability derivative were deflected a unit value. The calculation also differs depending on whether the user-requested stability derivative is restrained or unrestrained. In the restrained case, the accelerations and the displacements of the SUPORTed degrees of freedom are zero, whereas the unrestrained case has a complete set of displacements and accelerations. Stated in equation form, the pseudoloads of (2-210) that are obtained for the unrestrained derivatives are computed based on accelerations and displacements that result from a solution of the equation

$$\begin{bmatrix} (K_{ll}+K^a_{ll}) & (K_{lr}+K^a_{lr}) & (M_{ll}D+M_{lr}) \\ (D^TM_{ll}+M_{rl}) & (D^TM_{lr}+M_{rr}) & 0 \\ (D^TK^a_{ll}+K^a_{rl}) & (D^TK^a_{lr}+K^a_{rr}) & m_r \end{bmatrix} \begin{Bmatrix} u^{us}_l \\ u^{us}_r \\ \ddot{u}^{us}_r \end{Bmatrix} = -\begin{Bmatrix} K^a_{lx} \\ 0 \\ D^TK^a_{lx}+K^a_{rx} \end{Bmatrix} \begin{Bmatrix} u^{us}_x \end{Bmatrix} \tag{2-214}$$

where the us superscript indicates that the u_x variable and the response quantities are associated with unrestrained stability derivatives. The u_x vector has all of its rows set to zero except for the row associated with the variable of interest, which has a value of unity. Once the accelerations in the r-set and the displacements in the a-set have been computed, they can be recovered to the g-set using standard recovery techniques.

The unrestrained stability derivative calculation can be viewed as the solution of the third row of (2-214).

$$[STABU] = [m_r]\begin{Bmatrix} \ddot{u}^{us}_r \end{Bmatrix} = -[KAZ_x]\begin{Bmatrix} u^{us}_x \end{Bmatrix} - [KAZ_l]\begin{Bmatrix} u^{us}_l \end{Bmatrix} - [KAZ_r]\begin{Bmatrix} u^{us}_r \end{Bmatrix} \tag{2-215}$$

where the KAZ notation implies $D^T K_{li}^a + K_{ri}^a$. (2-215) represents a dimensional equation, with the nondimensionalization a function of the stability derivative of interest. The sensitivity of (2-215) can be performed on either of the two right-hand sides. The second equality has been chosen giving

$$[\Delta STABU] = [KAZ_l]\left\{\Delta u_l^{us}\right\} - [KAZ_r]\left\{\Delta u_r^{us}\right\} \tag{2-216}$$

where the sensitivities of the displacements are obtained from the solution of (2-210). The following derivation utilizes notation used in the SAERSENS subDMAP (see Aeroelastic Solution Sequences) and also notation already introduced in Unrestrained Stability Derivatives. The Δu_x term of (2-210) is zero so that the equation becomes

$$\begin{bmatrix} KSALL & KSALR & MSLR \\ M1RL & M1RR & 0 \\ KAZL & KAZR & MSRR \end{bmatrix} \begin{bmatrix} UDUL \\ UDUR \\ UDURDD \end{bmatrix} = \begin{bmatrix} DPSALU \\ PLMAZ \\ PLZ \end{bmatrix} \tag{2-217}$$

where $DPSALU$ is the l-partition of the $DPSAAU$ matrix that is, in turn, made up of the relevant columns from DPL and

$$UDUL = \Delta u_l \tag{2-218}$$

$$UDUR = \Delta u_r \tag{2-219}$$

$$UDURDD = \Delta \ddot{u}_r \tag{2-220}$$

$$[PLMAZ] = [D]^T[DML_l] + [DML_r] \tag{2-221}$$

$$[PLZ] = [D]^T[DPSALU] + [DPSARU] \tag{2-222}$$

The first row of (2-217) is solved for $UDUL$ to give

$$[UDUL] = -[ARLR][UDUR] - [AMLR][UDURDD] + [DUALP] \tag{2-223}$$

where:

$$DUALP = [KSALL]^{-1}[DPSALU] \tag{2-224}$$

Substituting into the second row of (2-217) gives

$$[M2RR][UDUR] + [M3RR][UDURDD] = [DTMP1] \tag{2-225}$$

where:

$$[DTMP1] = [PLMAZ] - [M1RL][DUALP] \tag{2-226}$$

Then

$$[UDUR] + [M4RR][UDURDD] = [DTMP2] \tag{2-227}$$

where:

$$[DTMP2] = [M2RR]^{-1}[DTMP1] \tag{2-228}$$

If the expression for $UDUL$ from (2-223) is substituted into the third row of (2-217), then

$$[K2RR][UDUR] + [MSRR - KAZL \cdot AMLR][UDURDD] = [DIPZ] \tag{2-229}$$

where:

$$[DIPZ] = [PLZ] - [KAZL][DUALP] \tag{2-230}$$

Then the expression for $UDUR$ from (2-227) can be substituted into (2-229) to give

$$[MIRR][UDURDD] = [PZF] \tag{2-231}$$

where:

$$[PZF] = [DIPZ] - [K2RR][DTMP2] \tag{2-232}$$

Given $UDURDD$ from (2-231), UDUR is recovered from (2-225) and $UDUL$ is recovered from (2-223). The dimensional stability derivative data are then calculated using

$$[DSTABU] = -[KAZL][UDUL] - [KAZR][UDUR] \tag{2-233}$$

The $DSTABU$ vector is passed in to module $DSARSN$ to compute the stability derivative sensitivities.

The restrained stability calculations are greatly simplified since u_r, u_x, and $\ddot{u}_r$ are all invariant in (2-210). Therefore, it is necessary only to solve for the sensitivity of u_l. (2-210) then becomes

$$[KSALL][DUALS] = [PLSTBL] \tag{2-234}$$

where $DUALS$ is Δu_l and $PLSTBL$ is a partition of the appropriate columns of the PA matrix.

The dimensional stability derivative vector is then computed using

$$[DSTABR] = -[KAZL][DUALS] \tag{2-235}$$

Flutter Sensitivity

The flutter design capability has been developed based on two key considerations:

1. The PK-flutter method is the most appropriate for flutter design.
2. The damping values obtained from the PK-flutter analysis are the most appropriate design responses.

The PK-flutter method performs the flutter analysis at user-specified velocities and is therefore ideal in a design task in that it allows the user to focus on a particular velocity range. The K- and KE-flutter methods, on the other hand, perform the flutter analysis at user-specified reduced frequencies with little control over the associated velocities.

The selection of damping values on the design response conforms to the design specifications that are applied to the flutter behavior of air vehicles. Further, the tedious and error-prone process of determining the flutter velocity is avoided with this approach. Finally, by constraining the damping values over a range of frequencies, the possibility of "hump modes" is addressed.

The eigenvalue problem for flutter is given in (2-172), as

$$\left[M_{hh}p^2 + \left(B_{hh} - \frac{1}{4}\rho\bar{c}VQ_{hh}^I/k\right)p + \left(K_{hh} - \frac{1}{2}\rho V^2 Q_{gg}^R\right)\right]\{u_h\} = 0 \tag{2-236}$$

The terms necessary for the constraint conditions and the derivation of the sensitivity are defined again here: these are the frequency ω and the transient decay rate coefficient γ (Note that the structural damping coefficient $g = 2\gamma$), and the complex eigenvalue $p = \omega(\gamma + i) = p_R + p_r$.

The design response that is used in MSC Nastran to address flutter instabilities is the decay coefficient γ. The sensitivity calculation for $\Delta\gamma$ is conceptually straightforward, but is algebraically intense. From the relations $\gamma = p_R/\omega$ and $p_I = \omega$, the derivative is expressed in terms of the real and imaginary parts of the eigenvalue as

$$\Delta\gamma = \frac{1}{\omega}(\Delta p_R - \gamma\Delta p_I) \tag{2-237}$$

It remains to determine the sensitivities of the real and imaginary parts of the eigenvalue. The formulation to be used requires the definition of additional notation:

$$\{v_g\} = [\phi_{gh}]\{v_h\} \tag{2-238}$$

is the left eigenvector in the global set,

$$\{u_g\} = [\phi_{gh}]\{u_h\} \tag{2-239}$$

is the right eigenvector in the global set, and

$$[F_{gg}] = \left[p^2 M_{gg} + p\left(B_{gg} - \frac{1}{4}\rho\bar{c}V\frac{Q^I_{gg}}{k}\right) + \left[K_{gg} - \frac{1}{2}\rho V^2 Q^R_{gg}\right]\right] = 0 \tag{2-240}$$

The F_{gg} matrix is shown in order to lead the discussion. Aerodynamic matrices are not available in the g-set and the discussion will show that they are not needed. The left eigenvector of (2-236) is required in the sensitivity analysis, which points out a requirement for an eigenvector extraction in the sensitivity phase that is in addition to the aeroelastic calculations currently performed. This is a relatively straightforward calculation since the eigenvalues of a matrix and its transpose are identical.

(2-236) can be recast as:

$$[\phi_{gh}]^T[F_{gg}][\phi_{gh}]\{u_h\} = 0 \tag{2-241}$$

Differentiating:

$$\begin{aligned} &2[\phi_{gh}]^T[F_{gg}][\Delta\phi_{gh}]\{u_h\} + [\phi_{gh}]^T[\Delta F_{gg}][\phi_{gh}]\{u_h\} \\ &+ [\phi_{gh}]^T[F_{gg}][\phi_{gh}]\{\Delta u_h\} = 0 \end{aligned} \tag{2-242}$$

The term containing $\{\Delta u_h\}$, the eigenvector sensitivity, is neglected in the following. This is equivalent to assuming that the normal mode eigenvectors adequately span the space over which the flutter responses vary.

A rigorous simplification results from premultiplying (2-242) by v_h^T. The left-hand eigensolution of the flutter equation gives $v_g^T F_{gg} = 0$ so that the third term in (2-242) becomes zero and the remaining equation is:

$$\{v_g\}^T[\Delta F_{gg}]\{u_g\} = 0 \tag{2-243}$$

expanding:

$$\begin{aligned} &\{v_g\}^T[p^2\Delta M_{gg} + p\Delta B_{gg} + \Delta K_{gg} + (2pM_{gg} + B_{gg})\Delta p]\{u_g\} \\ &- \{v_h\}^T\left[\frac{1}{4}\rho\bar{c}V\left(p\Delta\left(\frac{Q^I_{hh}}{k}\right) + \frac{Q^I_{hh}}{k}\Delta p\right) + \frac{1}{2}\rho v^2\Delta Q^R_{hh}\right]\{u_h\} = 0 \end{aligned} \tag{2-244}$$

By writing the expressions in the g-set, the sensitivities of the mass, damping, and stiffness matrices are available.

The computation of the sensitivities of the aerodynamic matrices is straightforward since the matrices are a function only of Mach number and reduced frequency. The Mach number is invariant in the calculation while the reduced frequency can vary. For the aerodynamic sensitivity calculation, it is convenient to introduce the following notation:

$$RQ_{hh} = \mathrm{Re}(Q_{hh}) \tag{2-245}$$

and

$$IQ_{hh} = \mathrm{Im}(Q_{hh})/k \tag{2-246}$$

The sensitivities are then computed as:

$$\Delta RQ_{hh} = \frac{\partial RQ_{hh}}{\partial k}\Delta k \tag{2-247}$$

$$\Delta IQ_{hh} = \frac{\partial IQ_{hh}}{\partial k}\Delta k \tag{2-248}$$

where $\Delta k = \bar{c}\mathrm{Im}(\Delta p)/(2V)$. To be rigorous, it should be noted that $\Delta RQ_{hh} \equiv \mathrm{Re}(\{v_g\}^T[G_{kg}^T \Delta Q_{kk} G_{kg}]\{u_g\})$. A similar result applies to ΔIQ_{hh}.

The sensitivity of the aerodynamic matrix with respect to the reduced frequency can be computed analytically based on the spline fit used for matrix interpolation. This fit expresses the aerodynamics as the weighted sum of invariant matrices, with the weighting functions a cubic function of the reduced frequency.

(2-244) can then be written as:

$$\begin{aligned}
&\{v_g\}^T[p^2 \Delta M_{gg} + p\Delta B_{gg} + \Delta K_{gg} + (2pM_{gg} + B_{gg})\Delta p]\{u_g\} \\
&- \{v_h\}^T\left[\frac{1}{8}\rho\bar{c}^2 p\mathrm{Im}(\Delta p)\frac{\partial IQ_{hh}}{\partial k} + \frac{1}{4}\rho\bar{c}VIQ_{hh}\Delta p\right. \\
&\left. + \frac{1}{4}\rho\bar{c}V\mathrm{Im}(\Delta p)\frac{\partial RQ_{hh}}{\partial k}\right]\{u_h\} = 0
\end{aligned} \tag{2-249}$$

(2-249) is a complex scalar equation with the complex Δp as the single unknown. The equation can be separated into its real and imaginary parts based on the following definitions:

$$PR + iPI = p \tag{2-250}$$

$$P2R + iP2I = p^2 = PR \cdot PR - PI \cdot PI - 2iPR \cdot PI \tag{2-251}$$

$$DPR + iDPI = \Delta p \tag{2-252}$$

$$MR + iMI = \{v_g\}^T[\Delta M_{gg}]\{u_g\} \tag{2-253}$$

$$BR + iBI = \{v_g\}^T[\Delta B_{gg}]\{u_g\} \tag{2-254}$$

$$KR + iKI = \{v_g\}^T[\Delta K_{gg}]\{u_g\} \tag{2-255}$$

$$GMR + iGMI = \{v_h\}^T[M_{hh}]\{u_h\} \tag{2-256}$$

$$GBR + iGBI = \{v_h\}^T[B_{hh}]\{u_h\} \tag{2-257}$$

$$AIR + iAII = \{v_h\}^T[IQ_{hh}]\{u_h\} \tag{2-258}$$

$$DAIR + iDAII = \{v_h\}^T\left[\frac{\partial IQ_{hh}}{\partial k}\right]\{u_h\} \tag{2-259}$$

$$DARR + iDARI = \{v_h\}^T\left[\frac{\partial RQ_{hh}}{\partial k}\right]\{u_h\} \tag{2-260}$$

Then the real and imaginary parts of (2-249) give the following two equations.

$$\begin{bmatrix} DF11 & DF12 \\ DF21 & DF22 \end{bmatrix}\begin{Bmatrix} DPR \\ DPI \end{Bmatrix} = \begin{Bmatrix} F1 \\ F2 \end{Bmatrix} \tag{2-261}$$

where

$$F1 = -P2R \cdot MR + P2I \cdot MI - PR \cdot BR + PI \cdot BI - KR \tag{2-262}$$

$$F2 = -P2R \cdot MI + P2I \cdot MR - PR \cdot BI + PI \cdot BR - KI \tag{2-263}$$

$$DF11 = BR + 2.0(PR \cdot GMR - PI \cdot GMI) - C4 \cdot AIR \tag{2-264}$$

$$DF21 = BI + 2.0(PR \cdot GMI - PI \cdot GMR) - C4 \cdot AII \tag{2-265}$$

$$DF12 = -DF21 - C8(PR \cdot DAIR - PI \cdot DAII) - C4 \cdot DARR \tag{2-266}$$

$$DF22 = DF11 - C8(PR \cdot DAII + PI \cdot DAIR) - C4 \cdot DARI \tag{2-267}$$

where $C4 = \rho\bar{c}V/4$ and $C8 = \rho\bar{c}^2/8$

All the matrices in these equations are real so that the scalar relationships are also real. The solution of (2-261) leads to Δp_R and Δp_I which are substituted into (2-237) to obtain the desired sensitivities.

In the case where the eigenvalue is real, the definition of the decay coefficient is different from $\gamma = p_R/\omega$. In this case it is given by $\gamma = p_R/ln2$ and the sensitivity becomes

$$\Delta\gamma = \frac{1}{ln2}\Delta p_R \tag{2-268}$$

Optimization with Aeroelastic Constraints

The foregoing aeroelastic sensitivities are calculated for each design variable, along with other structural sensitivities, in SOL 200 of MSC Nastran. When the constraints are all specified, aeroelastic and otherwise, a specific objective (cost) function, for example, weight, can be minimized via the optimization procedures in SOL 200 [see the *MSC Nastran Design Sensitivity and Optimization User's Guide* and Vanderplaats (1984) [Reference 62]]. Guidelines for selection of aeroelastic design variables and constraints are presented in Aeroelastic Modeling. Example problems illustrating optimization for strength and aeroelastic characteristics are presented in Aeroelastic Design Sensitivities and Optimization.

3 Aeroelastic Modeling

Overview

The MSC Nastran aeroelastic analysis and design capabilities are intended for the study of stability and response of aeroelastic systems. This User's Guide is one of MSC Nastran books that describe the MSC Nastran system and you are directed to in-depth discussion of many aspects of structural modeling and analysis that complement the material presented in this guide. This chapter deals primarily with aerodynamic data and the connection between structural and aerodynamic elements as well as the methods for stability and response analysis and design.

Some discussion of both structural and aerodynamic modeling is also included with the example problems in Static Aeroelastic Analysis Problems through Aeroelastic Design Sensitivities and Optimization.

"MSC Flightloads" on page page 103 provides a rudimentary description of a companion volume "*MSC FlightLoads and Dynamics User's Guide*" that describes the graphical user interface that can be used to generate aerodynamic models and view selected results. MSC FlightLoads is a companion product to the MSC Nastran aeroelastic offerings and so that, while it is hoped the user will treat the products in an integrated way, their documentation is distinct with minimal overlap.

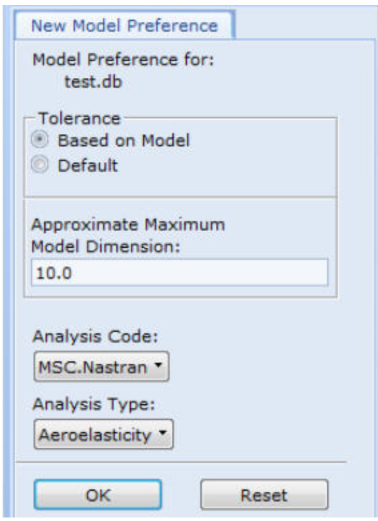
- Aerodynamic Modeling (in chapter 3) deals with the aerodynamic data. The selection of a good aerodynamic model depends upon some knowledge of the theory (see Internal Aerodynamic Theories, 15). Several aerodynamic theories are available; all assume small amplitude, quasi-steady or sinusoidal motions. Transient aerodynamic loads are obtained by Fourier methods.
- Interpolation from Structural to Aerodynamic Models deals with the interpolation from structural to aerodynamic degrees of freedom, and the interpolation methods include both linear and surface splines. These methods are usually superior to high-order polynomials because they tend to give smoother interpolations since they are based upon the theory of uniform beams and plates of infinite extent.
- Static Aeroelastic Analysis describes static aeroelastic analysis. The trim solution is obtained only in quasi-steady equilibrium at subsonic or supersonic speeds. Static and dynamic aerodynamic stability derivatives, as well as aerodynamic and structural loads, are also obtained along with structural element stresses and deflections. Aeroelastic divergence speeds of restrained vehicles may be found from the K- or KE-methods of modal flutter analysis, or they may be obtained from a special purpose static aeroelastic option. Divergence and flutter speeds of any vehicle may always be determined by the PK-method of flutter analysis.
- Flutter Analysis describes modal flutter analysis by the three available methods: the American (K) method, a streamlined version of the American method (KE), and the British (PK) method. After a vibration analysis, the flutter frequencies and dampings are obtained as functions of the velocity, and the relative modal amplitudes are found, except in the KE-method. The physical displacements in the vibration modes are also available for output.
- Dynamic Aeroelastic Response Analysis gives instructions for modal dynamic aeroelastic response analyses. These include frequency response, transient response, and random response analyses. The excitation may consist of applied mechanical forces using any aerodynamic theory or gusts with the Doublet-Lattice and ZONA51 theories only. The response parameters can include loads, stresses, and displacements.
- Aeroelastic Design Sensitivity and Optimization provides guidance for adding static aeroelastic and flutter constraints to the MSC Nastran optimization design procedure (SOL 200).

Main Index

MSC Flightloads

MSC Flightloads is an option within the MSC Patran product. It is invoked in Patran as part of the New Model Preferences form that appears when creating a new database.

When a new database is opened, the New Model Preferences form displays and the user can access FlightLoads by selecting Aeroelasticity as the Analysis Type; this allows for immediate aeroelastic modeling and analysis. If the user chooses an Analysis Type of Structural or Thermal, FlightLoads is subsequently accessed in an existing database through the Preferences/Analysis menu. FlightLoads coexists with the available structural and thermal analyses in the MSC Nastran Preference as an aeroelastic analysis.



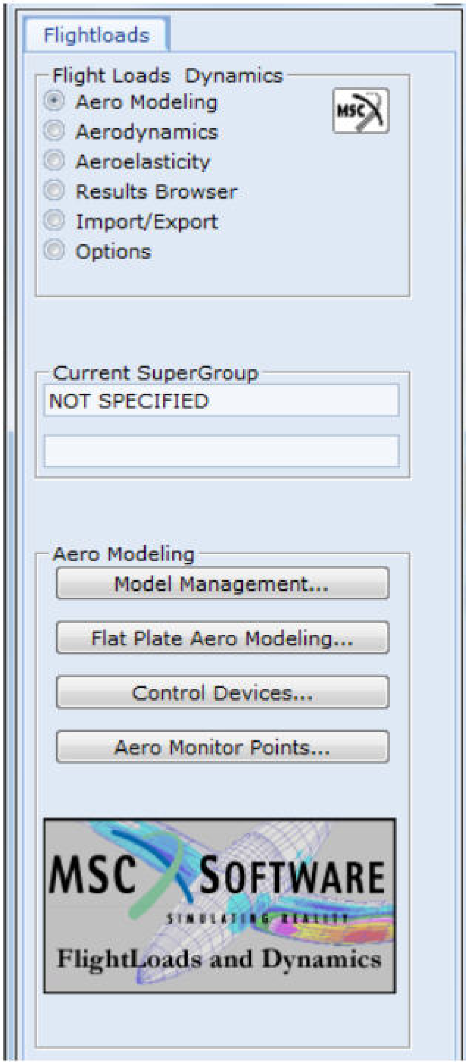
FlightLoads coexists with the available structural and thermal analyses in the MSC Nastran Preference as an aeroelastic analysis.

If you open the database with an analysis type other than Aeroelasticity, you can choose the **Preferences** option on the main form, and you can select the **Aeroelasticity Analysis** type. When the **Aeroelasticity** preference is selected, a menu is customized for MSC FlightLoads and Dynamics.

Many of the options available in a **Structural Analysis** type (such as LBCs and Materials) will disappear from the main menu. The Geometry is available in the main menu to assist the definition of the aerodynamic model.

If the FlightLoads is selected, it displays **MSC FlightLoads** and **Dynamics** main menu:

There are six modules in the main menu of Flightloads. Select an option to display the main form for that module.



The MSC FlightLoads and Dynamics User's Guide explains the menus that are accessed from this main menu. The next five chapters of this manual gives detailed information on each of the options. Note that the Options module is as part of the Model Management section.

A general description of each of the MSC FlightLoads and Dynamics main options are as follows:

- **Aero Modeling:** This module allows you to define the aerodynamic geometry, including wings, bodies and control surfaces. This supports the aerodynamics currently available in MSC Nastran to perform static aeroelastic analysis, namely the Doublet- Lattice (subsonic) and ZONA51 (supersonic) aerodynamics and flutter. Aero Modeling includes the management of various aerodynamic models, the creation and subsequent processing of the aerodynamic lifting surfaces and bodies, the definition of control systems, and various other model visualization and verification tools.
- **Aerodynamics:** This module allows you to define the aerodynamics as steady or unsteady and set global data.
- **Aeroelasticity:** This module is used to couple and subsequently analyze the aerodynamic and structural models. MSC FlightLoads and Dynamics provides for model evolution (that is, beam - stick to 3D FEM Structural models) and for the coexistence of multiple aerodynamic mesh representations. Data reuse is also supported. Aerodynamics and aeroelastic data can be archived for subsequent reuse in analysis. A variety of static aeroelastic analyses can be performed, including flexible trim, rigid trim and the calculation of flexible load increments.
- **Results Browser:** This option is a key feature of MSC FlightLoads and Dynamics. It allows you to view external loads on the aerodynamic and structural models, providing insight into the flight environment. The graphical display of these loads is extremely useful in spotting modeling errors or areas for model refinement. External loads data can reside in an aerodynamic or aeroelastic database, an MSC Patran database or an MSC Nastran results file.
- **Import/Export:** This option is used to support the extensive legacy information that exists for MSC Nastran aeroelasticity. You can import aerodynamic and spline models from an existing MSC Nastran bulk data file and subsequently manipulate this data using the Aero Modeling module. During typical usage, you can first populate the MSC Patran database with the structural model. This is done by using the File/Import function within the MSC FlightLoads Import function. Spline data cannot be imported unless the corresponding structural nodes are already in the database.
- **Options:** This final module is limited to a single panel that allows you to specify the aerodynamic coordinate system, starting element ID's and some tolerance information.

Aerodynamic Modeling

Internal aerodynamic elements (that is, those for which the aerodynamics are computed internally in MSC Nastran) are regions of lifting surfaces or bodies. Since the elements occur in regular streamwise arrays, the aerodynamic connection (`CAEROi`) Bulk Data entries have been designed to specify these arrays. The aerodynamic grid points associated with the elements in an array are generated internally in the program. Spline methods are used to interpolate aerodynamic grid point deflections to structural grid points.

Note:	The graphical user interface contained in MSC Flightloads of the previous section, can be used to generate the aero model and the spline while following all the guidelines described in this section.

For every aerodynamic problem, pertinent basic flight and geometric parameters are specified on one of two Bulk Data entries:

- The `AEROS` entry is used in static aeroelastic analyses
- The `AERO` entry is used in dynamic analyses.

A rectangular aerodynamic coordinate system must be identified. The flow is in the positive x-direction in this system and parallel to the plane of the aerodynamic elements. The use of symmetry or antisymmetry)is available to analyze structures that have both stiffness and inertial symmetry, to simulate ground effects, and to simulate wind tunnel wall effects. Any consistent set of units can be used for the dimensional quantities.

The types of elements available are shown in Table 3-1. Every `CAEROi` entry must reference an aerodynamic property (`PAEROi`) data entry that is used to list additional parameters. Tabulations of numbers or other defining parameters are sometimes required, depending on the selected aerodynamic method, and these are listed on `AEFACT` entries. These lists include division points (for unequal box sizes) and a variety of other parameter values.

Table 3-1 MSC Nastran Aerodynamic Elements

Attribute	Aerodynamic Theory					
	Doublet-Lattice Panel	Lifting Body (Interference)	ZONA51 - CPM Panel	Mach Box Surface	Strip Theory	Piston Theory
Bulk Data Entries	CAERO1 PAERO1	CAERO2 PAERO2	CAERO1 PAERO1	CAERO3 PAERO3	CAERO4 PAERO4	CAERO5 PAERO5
Mach Number	Subsonic	Subsonic	Supersonic	Supersonic	All	High Supersonic
Symmetry Options	Two Planes y = 0 z = 0	Two Planes y = 0 z = 0	One Plane y = 0	One Plane Required	None	None
Interaction	Panels and Bodies in the Same Group		Panels in the Same Group	Boxes on 1 Surface	None	None
Interconnection to Structure	Box Centers	Slender Body Centers	Box Centers	User Specified Locations	Strip 1/4-Chord	Strip 1/4-Cord
Displacement Components Used at Connection Points	3,5	3,5 z-Bodies 2,6 y-Bodies	3,5	3,5	3,5 and 6 for Control	3,5 and 6 for Control

Doublet-Lattice ZONA51 and CPM Panels

The configuration is divided into planar trapezoidal panels (macro-elements), each with a constant dihedral and with sides parallel to the airstream direction. These panels are further subdivided into *boxes* (see Figure 3-1), which are similarly configured trapezoids. The following are guidelines that are not enforced by the program; the user is expected to ensure adherence to these rules.

If a surface lies in (or nearly in) the wake of another surface, then its spanwise divisions should lie along the divisions of the upstream surface. The strips near the intersection of intersecting surfaces should have comparable widths. The aspect ratio of the boxes should approximate unity; less than three is acceptable in the subsonic case, and of order one is desirable in the supersonic case.

The chord length of the boxes should be less than 0.08 times the velocity divided by the greatest frequency (in Hz) of interest, that is, $\Delta x < 0.08\,V/f$

This is a requirement for approximately 12 boxes per minimum wavelength. However, no less than four boxes per chord should be used. Boxes should be concentrated near wing edges and hinge lines or any other place where downwash is discontinuous and pressures have large gradients. Concentrating boxes near hinge lines is a requirement of Potential Theory which neglects viscous effects; not increasing the concentration of boxes near hinge lines lowers the calculated control surface effectiveness and leads to closer agreement with experimental data (with the added benefit of reduced computational time).

The chord lengths of adjacent boxes in the streamwise direction should change gradually. A further discussion of the choice of models is found in Rodden, Harder, and Bellinger (1979) [Reference 50].

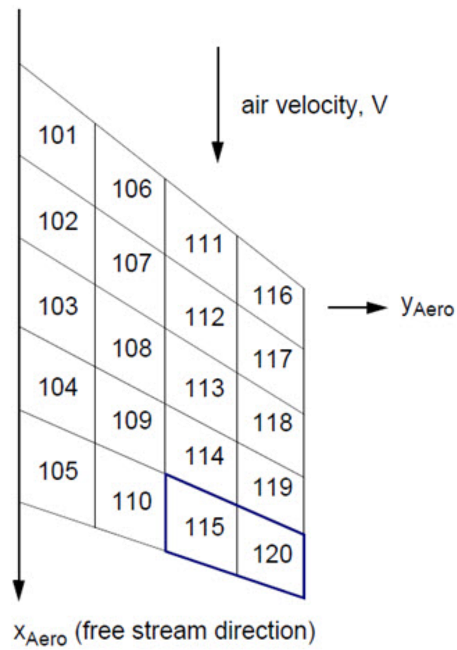


Figure 3-1 Aerodynamic Doublet-Lattice/ZONA51 Panel Subdivided into Boxes

The basic methodologies is shared between the three aero methods with the exception that the CPM method does not support triangular boxes while doublet lattice and ZONA51 do. Aerodynamic panels are assigned to interference groups. All panels within a group have aerodynamic interaction. The purpose of the groups is to reduce the computational effort for aerodynamic matrices when it is known that aerodynamic interference is important within the group but otherwise is negligible or to allow the analyst to investigate the effects of aerodynamic interference. Computational effort is no longer a significant consideration for most panel methods so that multiple interference groups are not required.

Each panel is described by a `CAERO1` Bulk Data entry. A property entry `PAERO1` must be used to identify associated interference bodies in the subsonic case. A dummy `PAERO1` entry is still required for subsonic analyses and for subsonic analyses without bodies. A body should be identified as a member of the interference group if the panel is within one diameter of the surface of the body. The box divisions along the span are determined either by specifying the number of equal boxes NSPAN, or by identifying (by LSPAN), the `AEFACT` data entry that contains a list of division points in terms of fractions of the span. A similar arrangement is used to specify divisions in the chordwise direction by choosing `NCHORD` or `LCHORD`.

The locations of the two leading edge points are specified in the coordinate system (CP) defined by the user (including basic). The lengths of the sides (chords) are specified by the user, and they are in the airstream direction (i.e. parallel to the x-axis of the aerodynamic coordinate system specified on the AERO or AEROS Bulk Data entry). Every panel must be assigned to some interference group (IGID). If all panels interact, then IGID must be the same for all panels.

Aerodynamic Grid Points

There are two sets of aerodynamic grid points.

- In the first set, there is an aerodynamic grid point with its associated degrees of freedom in plunge and pitch for each box within a given panel. These points are located at the center of each box and are automatically numbered and sequenced by the program. The lowest aerodynamic grid point number for a given panel is automatically assigned the same number as specified for the panel ID field on the CAERO1 entry starting with the box connected to point 1. The grid point numbers increase in increments of 1 (see the CAERO1 Bulk Data entry description) first in the chordwise direction and then spanwise over all boxes in the panel.

  In the example of Figure 3-1, the first set of grids goes from 101 to 120 while the second set goes from 101 to 130. You must be aware of these internally generated grid points and ensure that their numbers are unique with respect to any structural grid, scalar, and extra point IDs. The reason for this is that these aerodynamic points are used for output including displacements, plotting, matrix prints, etc. The local displacement coordinate system has component T1 in the flow direction and component T3 in the direction normal to the panel in the element coordinate system defined on the CAERO1 entry.

- In the second set of grid points, they are at the mesh points of the panel. For the second set of grid points, there is an aerodynamic grid point at each corner of the mesh. This is used for display surfaces and results in there being (NCHORD+1) * (NSPAN+1) grid points for each panel, where NCHORD is the number chordwise boxes and NSPAN is the number of spanwise boxes.

Slender and Interference Bodies

In subsonic problems, bodies are idealized as *slender* and *interference* elements in combination. The primary purpose of the slender body elements is to account for the forces arising from the motion of the body, whereas the interference elements are used to account for the interference among all bodies and panels in the same group. This is done by providing a surface through which the boundary condition of no flow is imposed. Bodies are further classified as to the type of motion allowed.

In the aerodynamic coordinate system, y and z are perpendicular to the flow. In general, bodies may move in both the y- and z-directions. Frequently, a body (for example, a fuselage) lies on a plane of symmetry and only z- (or y-) motion is allowed. Thus, any model may contain z-bodies, zy-bodies, and y-bodies. One or two planes of symmetry or antisymmetry may be specified. Figure 3-2 and Figure 3-3 show an idealization with bodies and panels.

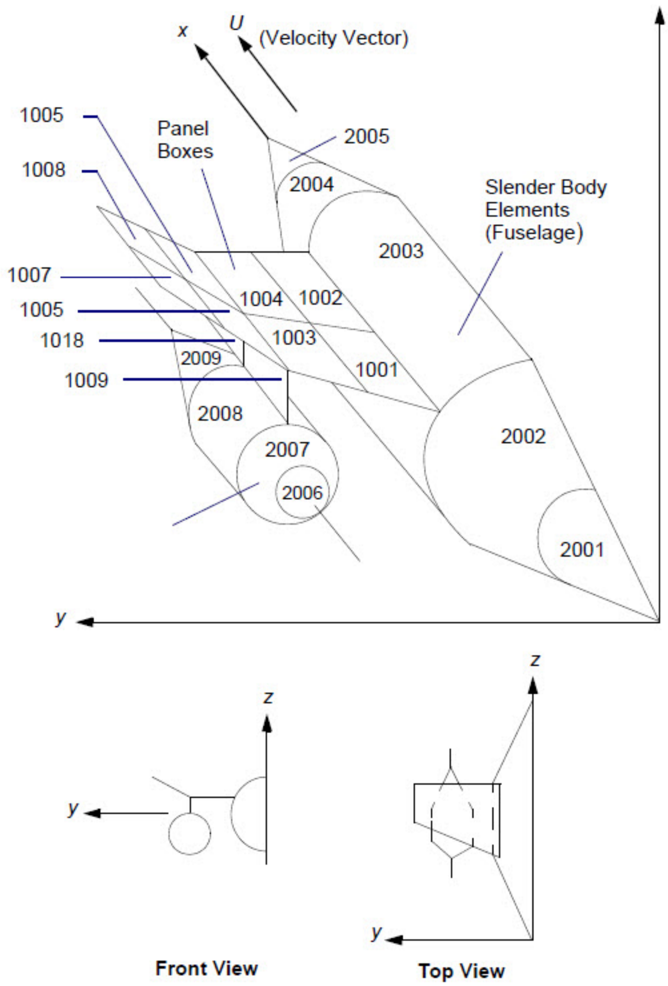


Figure 3-2 N5KA Bomber: Illustration of Boxes and Slender Body Elements

Figure 3-2 shows an example of the Illustration of Boxes and Slender Body Elements of the N5KA Bomber—with three panels, ten boxes, two bodies, nine slender body elements, and seven interference elements.

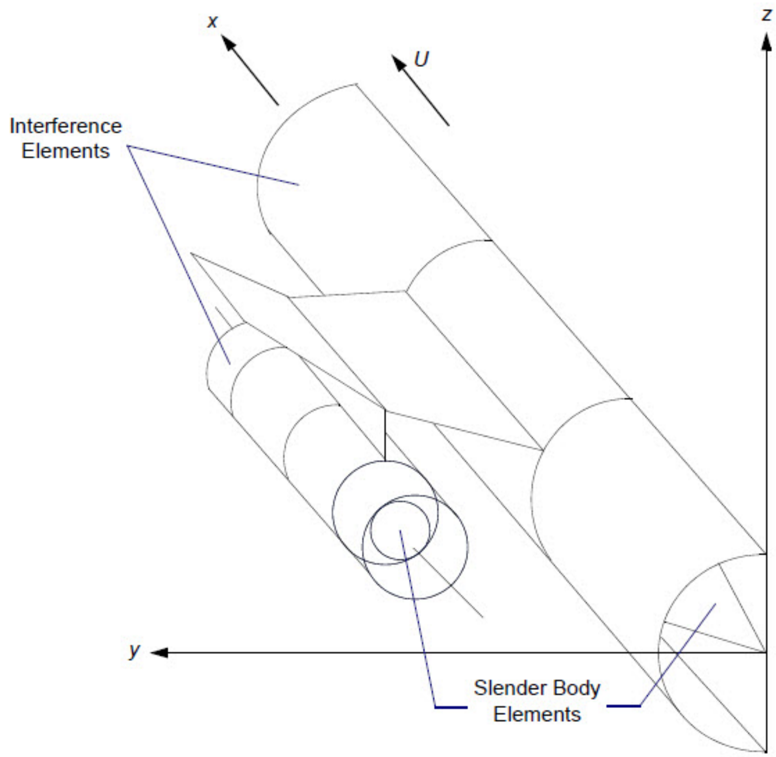


Figure 3-3 Illustration of Interference Elements.

Figure 3-3 shows an example of N5KA Bomber Example with Three Panels, Ten Boxes, Two Bodies, Nine Slender Body Elements, and Seven Interference Elements.

The `PAERO1` Bulk Data entry lists the IDs of all the bodies that are associated (that is, interfere) with a given Doublet-Lattice panel (`CAERO1` entry). The `CAERO2` entry specifies the geometry and divisions for the slender body and interference elements. The `PAERO2` entry provides orientation and cross-section data for the slender body and interference elements as well as the sampling data to account for the residual flow discussed later. The location of the body nose and the length in the flow direction are given.

The slender body elements and interference elements are distinct quantities and must be specified separately. At least two slender body elements and one interference element are required for each body. The geometry is given in terms of the element division points, the associated width, and a single height-to-width ratio for the entire body length. The locations of the division points may be given in dimensionless units or, if the lengths are equal, only the number of elements need be specified.

The body may be divided along its length unequally to characterize the lift distribution, noting that Slender Body Theory gives a lift proportional to the rate of change of cross-section area. Shorter elements should be chosen at the nose where the area is changing rapidly; longer elements can be used along cylindrical regions where the area is constant and intermediate length elements can be used in transition regions. The semi-widths of the slender body at interference element boundaries can be specified separately and are given in units of length. Usually the slender body semi-width is taken as zero at the nose and is a function of x, while the interference body semi-width is taken to be constant.

The interference elements are intended for use only with panels and/or other bodies, while slender body elements can stand alone. Grid points are generated only for the slender body elements. The first grid point is assigned the ID of the body corresponding to the element at the nose and other grid points are incremented by one. Ensure that the IDs of these generated grid points are greater than any structural grid, scalar point, extra point ID in the model, and any other aerodynamic grid point ID.

There are some requirements about bodies that have been imposed to simplify coding.

- All z-only bodies must have lower ID numbers than zy-bodies,.
- The zy-bodies must have lower ID numbers than y-only bodies.
- The total number of interference elements associated with a panel is limited to six.

Be cautious about using associated interference bodies as they significantly increase computational effort. A brief review of the Method of Images (and its approximations) follows before the implementation of the method in MSC Nastran is discussed.

The interference elements provide the basis for the internal image system that cancels most of the effects of the trailing vortices from the lifting surfaces. Because of the two-dimensional basis for this approximation (Thompson's Circle Theorem in Hydrodynamics), the body surface has been approximated by a constant elliptical cross-section cylinder called the interference tube, and it is this cylindrical tube that is divided into the interference elements.

All panels that intersect a body must be attached to the interference tube. Image locations are computed from the semi-width of the interference tube for all lifting surfaces associated with the body. The image is only computed if it lies between the front of the first interference element and aft of the last interference element for the associated body. Shorter interference elements are placed in regions of substantial interference, for example, near the wing-fuselage intersection; longer interference elements are placed in regions of less interference, and, of course, no elements are necessary where interference may be neglected.

An image is only computed if it lies between the front of the first interference element and the rear of the last interference element for the associated body. The division of the interference tube into interference elements is independent of the division of the body into slender body elements; the longitudinal locations of their end points are independent, although they can be chosen to be the same for convenience.

There is a residual flow through the body surface because the image system, being based on two-dimensional considerations, only partially cancels the flow through the body surface. It does not compensate for the effects of the bound vortices on the lifting surfaces or other bodies. Additional unknown residual doublets are located along the axis of the body, and, when determined, are added to the known doublet strengths of the slender body elements.

The residual flow is calculated by sampling the vertical or side velocity components from the net effect of the surface, slender body, and image vortices or doublets. The sampling is performed at various angular positions around the periphery of the elliptical interference tube at the end points of the interference elements. Two sampling patterns can be specified: the first might be dense for a region of strong interference, the other might

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be sparse for a region of weak interference (or the roles of the two may be interchanged). The strengths of the residual doublets are then determined to cancel the net velocity.

The calculation of the velocity field induced by the residual doublets requires knowledge of the geometry of the cross section of the slender body at the end points of the interference elements. However, experience shows that the residual flow is small compared to the slender body flow field so that the residual flow need not be represented accurately. This permits the further approximation of simply using the geometry of the constant cross-section interference tube in the calculation of the velocities induced by the residual doublets.

The contents of the various fields of the CAERO2 and PAERO2 data entries may now be summarized. The CAERO2 entry defines the slender body element end points and the interference body end points, the coordinates of the body nose, and the body length.

The PAERO2 entry defines the cross-sectional properties of the slender body and the interference tube:

- ORIENT specifies the direction(s) of motion
- WIDTH is the half-width of the interference tube
- AR is the body/tube aspect ratio (height/width)
- LRSB points to an AEFACT entry that lists the slender body half-widths at the end points of the slender body elements
- LRIB points to an AEFACT entry that lists the slender body half-widths of the end points of the interference elements (note that because the residual flow is small, as discussed above, leaving LRIB blank results in the velocities induced by the residual doublets being based on the interference tube cross-section, specified by WIDTH and AR, without significant error, and is recommended);
- LTH1 and LTH2 point to AEFACT entries that list the angles θ_1 and θ_2 (in degrees), respectively, around the periphery of the elliptical interference tube at which the residual flow velocity components are sampled and averaged, the first being the dense (or sparse) sampling and the second being the sparse (or dense) sampling;
- THIi and THNi list the first and last interference element (numbering beginning at one for each body) to use the θ_1 -array.

A discussion of two related problems follows:

The requirement for a constant cross-section interference tube may require moving the stabilizer (or wing). See Giesing, Kalman, and Rodden (1972a, §2.5.8 [Reference 19]). MSC Nastran can accommodate the requirements by specifying a stabilizer coordinate system, two sets of GRID points for the (same) stabilizer root and its fuselage connection, and MPCs constraining the motions of the two sets of GRIDs to be the same. This way, the structure can be modeled faithfully although the aerodynamic model is only approximate. This is illustrated in FSW Airplane with Bodies.

The idealization of a jet engine installation as a slender body results in a mass flow ratio through the engine of zero, since there is no flow through the body. Idealizing the engine as a ring-wing results in a mass flow ratio of unity, since all the flow goes through the tube. A typical mass flow ratio is 0.7, so a ring-wing representation is more appropriate.

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Mach Box Method

The supersonic lifting surface method for isolated surfaces that was originally included in the *Aeroelastic Addition to MSC Nastran* was a version of the Mach Box method developed for the NASA Space Shuttle. It has been superseded in MSC Nastran by ZONA51 for multiple interfering surfaces to maintain upward compatibility and for users who do not have the ZONA51 option (Aero II).

Mach Box aerodynamics may be used to compute unsteady supersonic aerodynamic forces for a planar, isolated wing at supersonic speeds. The surface (see Figure 3-4) may have a leading and/or trailing edge crank. There may be one or two adjacent trailing edge control surfaces. The inboard edge (side 1-2 on the CAERO3 entry) must be the plane of structural, mass, and aerodynamic symmetry.

The geometry of the planform is specified on the CAERO3 data entry. The two leading edge corners are located by the user. These, along with the flow direction, define the plane of the element. Up to 10 additional points are permitted to specify cranks and controls; these points are dimensional quantities using a coordinate system in the plane of the element and with its origin at point 1.

The recommended minimum number of Mach boxes is 80. The recommended minimum number in the flow direction is seven. The number of boxes in the flow direction is entered on the PAERO3 entry. The number of spanwise boxes is determined within the program as outlined in Internal Aerodynamic Theories since the total number of boxes depends on the Mach number, m , and will change for different Mach numbers. The number of Mach boxes in the flow direction may be computed as follows:

$$NBOX = \text{Int}\left[\frac{x_{max}}{\left(\dfrac{\beta y_{max}}{NSB - 0.5}\right)} + 0.999\right]$$

where:

β	=	$\sqrt{m^2 - 1}$
x_{max}	=	maximum chordwise dimension
y_{max}	=	maximum spanwise dimension

and Int( ) denotes the integer value of ( ), and NSB is the number of spanwise Mach boxes:

$$NSB = \text{Int}\left[\frac{\beta y_{max}}{\left(\dfrac{x_{max}}{NBOX0 + 0.5}\right)} + 0.5\right]$$

where $NBOX0$ = initial number of boxes selected

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To maintain aerodynamic matrices that are the same size for each m, k pair and that are generated at the same physical location, you have to ensure the following:

- Select a set of aerodynamic grid points (also called control points).
- On each aerodynamic surface there must be at least three noncolinear control points—more than three points are required to represent the modal deflections adequately.
- Three noncolinear control points provide sufficient geometric information for rigid body motion of the aerodynamic surface.

The `CAERO3` entry selects the points by defining their geometric location on the wing. These aerodynamic grid points are located using the coordinate system shown in Figure 3-4.

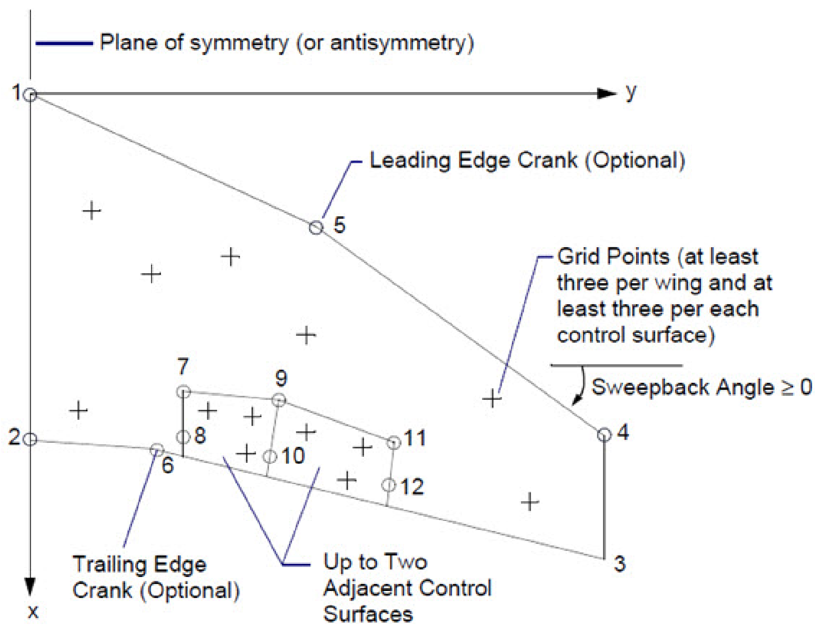


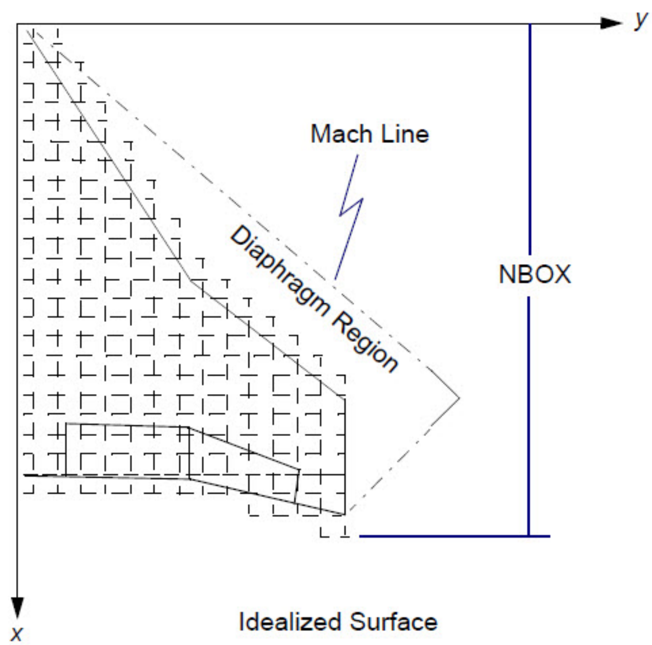
Figure 3-4 Mach Box Surface

The T3 component of these points is normal to the plane of the element. Additional lists of at least three points are needed for each optional control surface that is included. These aerodynamic grid points are numbered starting with the ID field of the CAERO3 entry, which must be a larger ID number than any `GRID`, `SPOINT`, or `EPOINT ID` in the model. Interpolation from the Mach box centers to determine deflections and slopes at these designated control points is performed with surface spline routines within the program and requires no input from the user.

The following restrictions apply to the Mach Box method:

- The edge 1-2 is taken as a plane of structural, mass, and aerodynamic symmetry; either symmetric or antisymmetric motions can be considered.
- Both leading edge and hinge line sweepback angles must be greater than or equal to zero.

- If a leading edge crank is not present, then x_5, y_5 do not have to be input.
- If a trailing edge crank is not present, then x_6, y_6 do not have to be input.
- A trailing edge crank cannot be located on the trailing edge of a control surface. It must be located inboard of the inboard surface, outboard of the outboard surface, or exactly at the junction between the two control surfaces.
- All control surface side edges must be parallel to the flow or swept inward.
- Points 8, 10, and 12 are used with Points 7, 9, and 11, respectively, to define the control surface edge, and they must be distinct from Points 7, 9, and 11, but with one exception they do not have to lie on the wing trailing edge. The program will calculate new Points 8, 10, and 12 for the wing trailing edge. The exception is that Points 8, 10, or 12 must be located on the trailing edge if the trailing edge is cranked at the side edge of a control surface.
- When only one control surface is present, it must be control surface one.
- If the second control surface is not present, then x_{11}, y_{11} and x_{12}, y_{12} are not required as input.
- If no control surfaces are present, then x_i, y_i (i = 7 through 12) are not required as input.
- No aerodynamic balance for the control surfaces has been included in the program.
- The number of chordwise boxes used as input (`NBOX`) to the program should be carefully selected to provide at least 80 boxes on the wing but `NBOX` cannot exceed 50. `NBOX` is the number of chordwise boxes between the most forward point and the most aft point on the lifting surface, as shown in Figure 3-5.
- If the maximum number of allowable boxes (500 on the main surface, 200 on each control surface) is exceeded, the program will reduce the number of chordwise boxes one at a time until the number of boxes is under the allowable limit.




```
                GRAPHIC DISPLAY OF REGIONS ON MAIN SEMISPAN
MACH NUMBER  1.300     BOX WIDTH     .052064     BOX LENGTH     .043248

               SS                                       S  MAIN
               SS.                                      1  CNTRL1
               SSS.                                     2  CNTRL2
               SSS..                                    .  DIAPHRAGM
               SSSS..                                   ;  WAKE
               SSSS...
               SSSSS...
               SSSSS....
               SSSSSS....
               SSSSSS.....
               SSSSSSS.....
               SSSSSSS......
               SSSSSSSS......
               SSSSSSSS......
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               SSSSSSSSSSSSS......
               SSSSSSSSSSSSSS......
               SSSSSSSSSSSSSS......
               SS1111122SSSSS.....
               SS111112222SSS....
               SS1111122222SS...
               SS1111122222SS..
                         22SS.
                            S
```

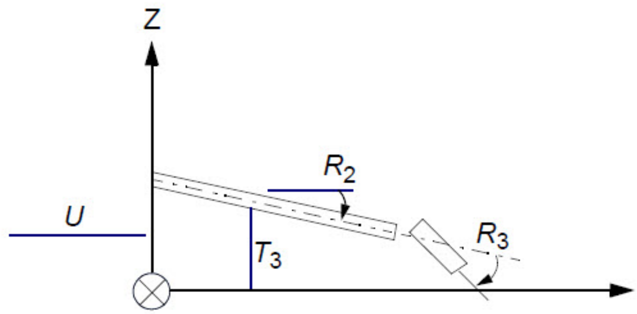
Generated Surface

Figure 3-5 Mach Box Surface Showing Mach Boxes and Diaphragm Region

Strip Theory

Modified Strip Theory can be used for unsteady aerodynamic forces on a high aspect ratio lifting surface, although it is less accurate than the available lifting surface theories. Each strip may have two or three degrees of freedom. Plunge and pitch are always used, and rotation of an aerodynamically balanced control surface is optional. If a control surface is present, either a sealed or an open gap may be used.

The planform (which may have several strips in one macro-element) is specified on a CAERO4 Bulk Data entry. A sample planform is as shown below.



The user supplies the two leading edge corner locations and the edge chords as dimensional quantities. Edge chords are assumed to be in the flow direction. All additional geometry (box divisions, hinge locations, etc.) are given in dimensionless units. Multiple CAERO4 entries may be used if there are several surfaces or cranks.

A grid point is assigned to each strip, and is assigned an ID starting with the CAERO4 entry ID and incrementing by one for each strip. The plunge (T3) and pitch (R2) degrees of freedom have the conventional definition. When a control surface is present, the R3 degree of freedom has a nonstandard definition, in the case of the relative control rotation. When interconnecting with the structure, the ordinary (surface or linear) splines can be used for T3 and R2, but a special method (see SPLINE3 data entry) is used for the relative control rotation.

The parameters such as the lift curve slope or the lag function may be varied to account approximately for finite-span effects (three-dimensional flow) and Mach number by AEFACT Bulk Data entry selection from PAERO4. The AEFACT Bulk Data entry format used by Strip Theory is shown in the remarks on the PAERO4 Bulk Data entry. The user may request a Prandtl-Glauert (compressibility) and/or a sweep correction to the value of the lift curve slope. The lag function depends upon the local (that is, using the chord of the strip) reduced frequency; for incompressible flow, it is the Theodorsen function $C(k)$. An approximate form for this function is given by

$$C(k) = \sum_{n=0}^{N} \frac{b_n}{1 - i\beta_n/k} \tag{3-1}$$

in which $\beta_0 = 0$, and may be selected for computing variations on the Theodorsen function that account for compressibility and finite span effects. The choice of parameters b_n and β_0 is left to the user to select values suitable for the requirement. Bisplinghoff, Ashley, and Halfman (1955, pp. 350, 394) [Reference 8] give values for various Mach numbers and aspect ratios.

An example of strip theory, lifting surface planform is shown in Figure 3-6.

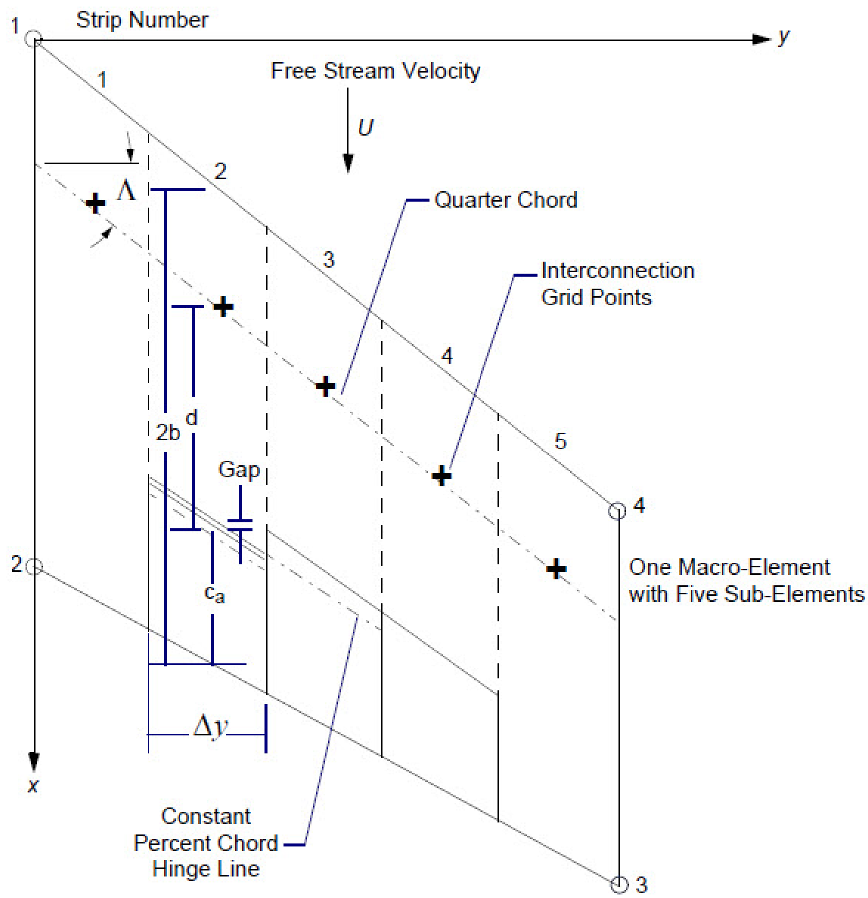


Figure 3-6 Strip Theory Example Lifting Surface

Piston Theory

Piston Theory in MSC Nastran is a form of strip theory taken from Rodden, Farkas, Malcom, and Kliszewski (1962) [Reference 47]who considered a rigid chord airfoil with an aerodynamically unbalanced rigid control surface.

The aerodynamic forces are computed from third-order Piston Theory, which is valid for large Mach numbers $m^2 \gg 1$, or sufficiently high reduced frequency $m^2k^2 \gg 1$.

Although the latter condition may be met in subsonic flow, the primary application of Piston theory is in high supersonic flow. The coefficients of the point-pressure function (relating local pressure to local downwash) may be modified to agree with the Van Dyke theory for a rigid chord and to account for sweepback effects. The resulting strip parameters will depend upon the wing thickness distribution and spanwise variation of initial angle of attack, both of which must be supplied by the user. If a control surface is present, it is assumed to have no aerodynamic balance.

Geometry specification and interconnection points follow the same rules as for Strip Theory. The additional information about angle of attack and thickness is input on AEFACT data entries that are referenced by the CAERO5 and PAERO5 data entries. The AEFACT data entry formats used by Piston Theory are shown in the Remarks on the PAERO5 data entry. If thickness integrals are input on AEFACT data entries, they must be calculated according to the thickness integral definitions on the CAERO5 data entry.

The effect of wing thickness is to move the local aerodynamic center forward of the midchord; the effect of initial (trim) angle of attack is to move the local aerodynamic center aft toward the midchord. Conservative flutter speed predictions should result if the angle of attack is assumed to be zero.

Chordwise flexibility (camber) can be approximated using multiple CAERO5 entries. Two examples (HA145G and HA145HA) illustrate this technique in Flutter Analysis Problems.

External Aerodynamic Mesh

The preceding portion of the Aerodynamic Modeling has dealt with models that are generated internally within MSC Nastran. There is also support for inputting an aerodynamic mesh using `AEGRID` entries to define the mesh points and `AEQUAD4` and `AETRIA3` elements to define the connectivity. There are no requirements that the grids be aligned in the streamwise direction in this case.

Each AEGRID has 6 degrees of freedom with the translational degrees of freedom being in the k-set. This implies that pressures, forces and displacements can be generated at the grid points for these degrees of freedom. An external mesh cannot be combined with an internal aero mesh in the same bulk data file, but Section xxx indicates how two meshes can be accommodated in a single analysis by combining the output datablocks from a run with an external aerodynamics with a subsequent run that has an internal aero model.

The connectivity data (that is, `AEQUAD4` and `AETRIA3`) are used for display and for converting user input aerodynamic pressures at the grid points to aerodynamic forces at these same grid points using PLOAD4-like methodology. The `CMPID` provided on these two entries is used by the spline entries to identify the aero panel that participates in the splining.

Ordering of J- and K-Set Degrees of Freedom

As detailed in Aerodynamic Data Input and Generation, the aerodynamic models used in MSC Nastran generate two sets of data, namely, the j-set and the k-set. Typically, the user does not have a need to be able to determine which member of a matrix belongs to a particular aerodynamic element.

The Case Control commands for pressures and forces (APRES and AEROF) are expressed in terms of the ID numbers input on the CAEROi entry. Similarly, if DMIJ or DMIK data entries are used to input pressure or force data, the grid ids and components listed on these entries are derived from the user defined ID's. If, however, the user has a need to manipulate matrices generated in MSC Nastran (for example, to generate running loads along a wing structure) the relationship between the matrix terms and the element locations is required.

For internal aerodyanmic methods, the order of both sets is driven by the ACPT data block (see Selected Aeroelastic Data Blocks), each record of which corresponds to a CAEROi Bulk Data entry.

For Strip Theory and Piston Theory, the k-set and j-set degrees of freedom are two aerodynamic points per strip (three per strip, if there is a control surface corresponding to: (1) plunge at the strip quarter chord, (2) rotation at the strip quarter chord, and (3) rotation of the control surface. Forces and moments are then (1) lift at the strip quarter chord, (2) pitching moment about the strip quarter chord, and (3) hinge moment about the control surface hinge line.

For the Mach Box aerodynamic theory, the number of j- and k-set degrees of freedom are identical and are equal to the number of user-defined structural interpolation points. Points on the wing are given first, followed by points on the first (optional) controls surface, and then points on the second (optional) control surface.

For External Aerodynamics generated based on AEGRID entries, the j- and k- sets are the same and are equal to three times the number of AEGRID entries and are in ascending order of AEGRID id. The degrees of freedom per grid correspond to translations. Pressures are input in the j-set and are input in the aerodynamic coordinate system with up to three components in the x, y and z directions. Similarly, forces are input in the k-set and can have up to three non-zero components in the x,y and z directions in the aerodynamic coordinate system.

As detailed in Aerodynamic Data Input and Generation, the location of the j-set and k-set degrees of freedom differ for the Doublet-Lattice and ZONA51 aerodynamic theories. When the Doublet-Lattice method includes bodies, the number of degrees of freedom in the two sets differs as well. Figure 3-7 provides the algorithm for determining k-set degrees of freedom while Figure 3-8 provides the algorithm for determining j-set degrees of freedom.

```
For each group (ACPT Record)
        For each CAERO1 entry
                For each box
                        Displacement of Box
                        Rotation of Box
                Repeat for each box
        Repeat for each CAERO1 entry in group
        For each CAERO2 with z orientation
                For each element
                        Displacement of z element
                        Rotation of z element
                Repeat for each element
        Repeat for each CAERO2 element in group with z
        orientation
        For each CAERO2 with zy orientation
                For each element
                        Displacement of y element
                        Displacement of z element
                        Rotation of y element
                        Rotation of z element
                Repeat for each element
        Repeat for each CAERO2 element in group with zy
        orientation
        For each CAERO2 with y orientation
                For each element
                        Displacement of y element
                        Rotation of y element
                Repeat for each element
        Repeat for each CAERO2 element in group with y
        orientation
Repeat for each group (ACPT Record)
```

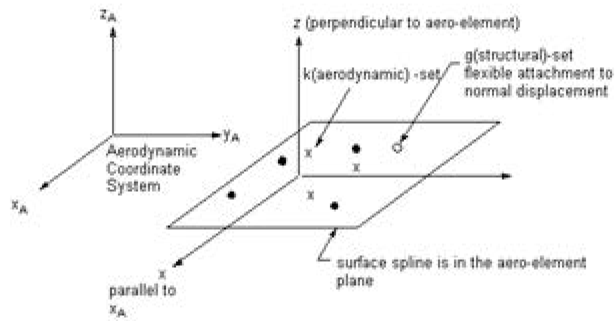
Figure 3-7 Order of k-Set DOF with Doublet-Lattice with Bodies and ZONA51

```
For each group (ACPT Record)
        For each CAERO1 entry
                For each box
                        Displacement of control point
                Repeat for each box
        Repeat for each CAERO1 entry in group
        For each CAERO2 with z orientation
                For each interference body
                        Displacement of control point
                Repeat for each interference body
        Repeat for each CAERO2 element in group with z orientation
        For each CAERO2 with zy orientation
                For each interference body
                        Displacement of control point in z direction
                Repeat for each interference body
        Repeat for each CAERO2 element in group with zy orientation
        For each CAERO2 with zy orientation
                For each interference body
                        Displacement of control point in y direction
                Repeat for each interference body
        Repeat for each CAERO2 element in group with zy orientation
        For each CAERO2 with y orientation
                For each interference body
                        Displacement of control point
                Repeat for each interference body
        Repeat for each CAERO2 element in group with y orientation
        For each CAERO2 with z orientation
                For each slender body element
                        Displacement of control point
                Repeat for each slender body element
        Repeat for each CAERO2 with z orientation
        For each CAERO2 with zy orientation
                For each slender body
                        Displacement of control point in z direction
                Repeat for each slender body
        For each CAERO2 with zy orientation
        Repeat for each CAERO2 element in group with zy orientation
                For each slender body
                        Displacement of control point in y direction
                Repeat for each slender body
        Repeat for each CAERO2 element in group with zy orientation
        For each CAERO2 with y orientation
                For each slender body
                        Displacement of control point
                Repeat for each slender body
        Repeat for each CAERO2 element in group with y orientation
Repeat for each group (ACPT record)
```

Figure 3-8 Order of j-Set DOF with Doublet-Lattice with Bodies and ZONA51

Interpolation from Structural to Aerodynamic Models

The interpolation from the structural to aerodynamic degrees of freedom is based upon the theory of splines (Figure 3-9). High aspect ratio wings, bodies, or other.



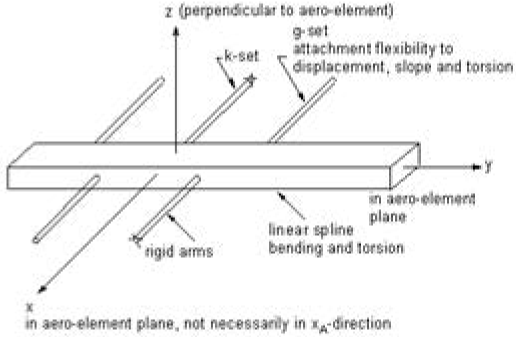


Figure 3-9 Splines and Their Coordinate Systems

beam-like structures should use linear splines (SPLINE2, SPLINE4, SPLINE6). Low aspect ratio wings, where the structural grid points are distributed over an area, should use surface splines (SPLINE1, SPLINE5, SPLINE7). Several splines can be used to interpolate to the boxes on a panel or elements on a body. In general, each aerodynamic box or element can be referenced by only one spline, but this limitation can be ignored if spline blending is employed. Any box or body element not referenced by a spline will be "fixed" and have no motion, and forces on these boxes or element7s will not be applied to the structure.

For all types of splines, the user must specify the structural degrees of freedom and the aerodynamic points involved. The degrees of freedom utilized at the grid points include only the normal displacements for surface splines. For linear splines, the normal displacements are always used and, by user option, torsional rotations and/or slopes may be included.

The SPLINE1, SPLINE5 and SPLINE6 data entries define a surface spline. These can interpolate for any "rectangular" subarray of boxes on a panel. For example, one spline can be used for the inboard end of a panel and another for the outboard end.

The selection of the aerodynamic points to be splined can vary based on the type of surface spline employed. For the SPLINE1, the user identifies a trapezoid of boxes by specifying the first and last ID of the trapezoid. For the SPLINE4 and SPLINE6 entries, the user specifies an AELIST entry, which in turn specifies identifies the aero points in a fashion that is a function of the type of aerodynamics being used. For the internal methods, this is a list of the aerodynamic boxes while for external aerodynamics specified using an aero mesh comprising AEGRID, AEQUAD4, AETRIA3 entries, it is a list of AEGRID's. For the Mach Box method, all entries refer to the x,y pairs identified on AEFACT entries invoked by the CAERO3 entry.

A parameter DZ is used to allow smoothing of the spline fit. If $DZ = 0$ (the recommended value), the spline will pass through all deflected grid points. If $DZ > 0$, then the spline (a plate) is attached to the deflected grid points via springs, which produce a smoother interpolation that does not necessarily pass through any of the points. The flexibility of the springs is proportional to DZ.

Four different methods of surface splines can be invoked with the METH field on the linear entries: IPS, TPS, FPS and RIS (infinite, thin, finite plate and radial interpolation spline, respectively). For the flat plate aerodynamics, there is little benefit from selecting the TPS. If the TPS is selected and all the grids are coplanar, the algorithm automatically reverts to IPS in any case. The FPS method is believed to provide improved behavior relative to the two infinite splines since it is better able to handle the deformation patterns at the edge of the aerodynamic panel. It is therefore recommended that the FPS be selected, but that the other two methods are available as a fallback if FPS performance is not satisfactory. When the FPS method is selected, you can specify the density of the interpolating mesh using the NELM, MELM describers as an optional continuation line. The default of NELM = MELM = 10 is felt to be adequate.

The USAGE flag on the spline entries identifies whether the spline is to be used to transform forces, displacements or both (FORCE, DISP or BOTH). The BOTH option is often acceptable, but the other options provide the ability to tailor the splining to the application. Since the force transformation imposes loads on the structure, it is reasonable to select grid points that can withstand this loading without severe deformations. The displacement transformation requires an accurate representation of the overall deformation pattern, so it is quite conceivable that a different set of grids from the force transform would be the most appropriate.

The SPLINE6 entry is an extended surface spline capability that has been provided for general interpolation between two meshes. Theoretically, both of the surfaces can be structural with VSTYPE=STRUC, but none of the current DMAP solutions provide for structure to structure splining. The description of this entry in the *MSC Nastran Quick Reference Guide* provides extensive information on the many parameters associated with this entry and also indicates that most of them have defaults which should be adequate.

The SPLINE2, SPLINE5 and SPLINE7 data entries define linear splines. As can be seen from Figure 3-9, these are a generalization of a simple beam spline to allow for interpolation over an area. They correspond to the frequently used assumption of the "elastic axis" in which the structure is assumed to twist about the axis such that the airfoil chord perpendicular to the axis behaves as if it were rigid. The portion of a panel to be interpolated and the set of structural points are determined in the similar manner as with the surface splines. However, a coordinate system must also be supplied to determine the axis of the spline (which is the elastic axis of the virtual beam); a coordinate system with its Y-axis collinear with the spline axis is required. That coordinate system should be somewhere near the true elastic axis and approximately aligned with it (e.g., swept if the elastic axis is swept). Since the spline has torsion and bending flexibility, the user may specify the ratio DTOR of flexibilities for a wing as a representative value of $(EI)/(GJ)$; the default value for this ratio is 1.0. The attachment flexibilities, D_x, $d_{\theta x}$, and $D_{\theta y}$ allow for smoothing, but usually all values are taken to be zero. When the attachment flexibilities are taken to be zero, the spline passes through all of the connected grid points and the value of the ratio DTOR has no effect. In the case where the structural model does not have one or both slopes defined, the convention $DTHX = -1.0$ and/or $DTHY = -1.0$ is used. When used with bodies, there is no torsion and the spline axis is along the body so that a user input coordinate system is not required.

There are special cases with splines where attachment flexibility is either required or should not be used. The following special cases should be noted:

1. Two or more grid points, when projected onto the plane of the element (or the axis of a body), may have the same location. To avoid a singular interpolation matrix, a positive attachment flexibility must be used (or better yet, only one grid point selected at that location).
2. With linear splines, three deflections with the same spline Y-coordinate over determine the interpolated deflections since the perpendicular arms are rigid. A positive DZ is needed to make the interpolation matrix nonsingular.
3. With linear splines, two slopes (or twists) at the same Y-coordinate lead to a singular interpolation matrix. Use $DTHX > 0$ (or $DTHY > 0$) to allow interpolation.
4. For some modeling techniques, i.e., those which use only displacement degrees of freedom, the rotations of the structural model are constrained to zero to avoid matrix singularities. If a linear spline is used, the rotational constraints should not be enforced to these zero values. When used for panels, negative values of DTHX will disconnect the slope, and negative values of DTHY will disconnect the twist. For bodies, DTHY constrains the slopes since there is no twist degree of freedom for body interpolation.

The USAGE flag on the linear spline entries performs the same function as on the surface splines.

The SPLINE5 bulk data entry is very similar to the SPLINE2 entry. The difference is the use of a list of aerodynamic elements rather than using "first box - last box" logic.

The SPLINE7 a linear spline that creates virtual bars along a user defined axis and then uses RBE2 and RBE3 elements to connect the aerodynamic and structural mesh. By default, all six degrees of freedom are included in the splining, but the METHOD field can be set to FBS3 to limit the map only translational degrees of freedom.

Miscellaneous Spline Options

The remaining spline options are briefly described here. The SPLINE3 provides a user specified linear relationship (like an MPC) for any aerodynamic grid point. It is felt to be primarily useful for control surfaces.

The SPLINRB entry is provided to transfer the aerodynamic loads to exactly six structural degrees of freedom. A scenario where this could be useful is when the aerodynamic model contains a surface that has no underlying structure (e.g., there is a horizontal stabilizer in the aerodynamic model but the finite element model only contains a wing). The six DOF's must define statically determinate supports.

The SPLBLND1 and SPBLND2 provide a means of blending the forces on aerodynamic grid points to create a smooth deformation pattern that may be critical in CFD applications. Although developed for external aerodynamics, this support of blending can be extended to internal aerodynamic methods by setting PARAM MLTSPLIN = 1 on the MDLPRM bulk data entry.

Two different blending methods are provided (plus if grids overlap without a SPBLNDx entry, the results are averaged). For the SPBLND1, the user identifies the two splines that are being blending by identifying a reference grid and two distances that define the strip over which blending is to occur. As shown in the *MSC Nastran Quick Reference Guide,* different weighting options (average, linear and cubic) are available and the spline that is invoked by the SID1 field can be a blended spline.

The SPBLND2 is similar, but now a curve of aerodynamic grids is used to define a reference location for the blending that takes place using the two distance provided relative to the curve. Only linear or cubic weighting is available with this option.

The SPRELAX entry is related to the blending options just described in that it provides a way of minimizing discontinuities at spline boundaries based in a user defined curve and a reference distance over which the relaxation applies.

The SPLINEX entry enables you to incorporate a spline technique that is not available by any of the MSC Nastran supplied methods. It may be that you are a researcher who is investigating spline techniques and wants a platform to check out the behavior of your developed spline or perhaps you have been made aware of some method that you feel is promising for your application. The SPLINEX provides data that needs to be passed to the client server and it returns the spline matrix based on the algorithm that you provide and implement. There is some discussion in the MSC Nastran Installation and Operations Guide that explains how this capability that makes references to further files that are available with the MSC Nastran Installation that can guide you in developing this service. It is remarked that you may need assistance from MSC in implementing your own spline methodology.

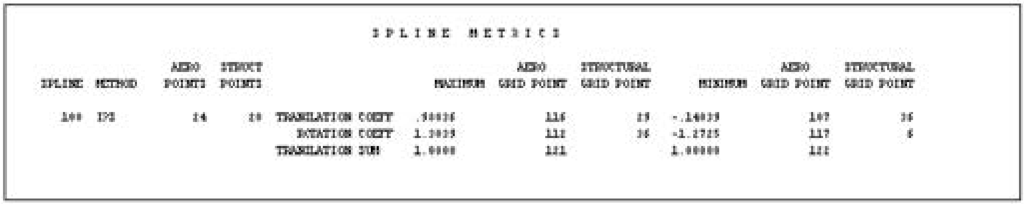
Spline Metrics

This final subsection provides a short description of a resource that is available in MSC.Nastran for evaluating the quality of the splines. It entails activating special prints within the MSC.Nastran that provide summary information for each of the splines.

The special prints are invoked by setting a system cell at the top of the MSC.Nastran input file using:

NASTRAN SPLINE_METRICS

With this input, summary information on the spline is created and printed in the .f06 output from the run. An example of this output is given in Figure 3-10.



S P L I N E   M E T R I C S

SPLINE	METHOD	AERO POINTS	STRUCT POINTS		MAXIMUM	AERO GRID POINT	STRUCTURAL GRID POINT	MINIMUM	AERO GRID POINT	STRUCTURAL GRID POINT
100	IPS	24	10	TRANSLATION COEFF	.90026	116	29	-.14039	107	36
				ROTATION COEFF	1.3035	112	36	-1.2725	117	6
				TRANSLATION SUM	1.0000	121		1.00000	122	

Figure 3-10 Spline Metrics Example

The output first lists the spline id and its type followed by the number of aero points and structural points that are being used in the spline. This is followed by two sets of tables that provide information on the maximum value and the minimum value for the translational and rotational coefficients in the spline matrix. It is difficult to assign physical meaning to the rotational coefficients, but the translational coefficients can be thought as a percentage of force that is being transformed for the aero/structural grid point listed. If the two sets of grids were identical in number and location, the max translation coefficient would be 1.0 and the min would be 0.0. If the meshes are not coincident, an estimate of the average coefficient value is given by the ratio of the number of aero points to the number of structural points. The maximum and minimum values would be somewhat above and below this number and judgment is required to determine if the values indicate problems with the spline. If the maximum value differs from the average value by over an order of magnitude, it may be beneficial to refine the spline in the area of the offending aero/structure pair. (Note that "refinement" may require removing one or more "nearly coincident" structural points -- a common cause of large couples.) A similar comment applies if the minimum value has an change of sign from the average and is greater in magnitude by over a factor of ten.

The matrix print shown above also prints the maximum and minimum sums of the spline matrix. Theoretically, each translation sum should be 1.0 and each rotational sum should be numerically 0.0 to indicate equilibrium. Experience has indicated that this is always the case for nonsingular splines. Perhaps the best way of assessing the quality of the splinning is to use the verify option within the Aero-Structure Coupling description of the *MSC Flightloads and Dynamics User's Guide*.

Static Aeroelastic Analysis

Static aeroelastic analysis is intended to obtain both structural and aerodynamic data. The structural data of interest include loads, deflections, and stresses. The aerodynamic data include stability and control derivatives, trim conditions, and pressures and forces. The analysis presupposes a structural model (both stiffness and inertial data), an aerodynamic model, and the interconnection between the two.

The requirements for static aeroelastic analysis beyond those for the structural and aerodynamic models are nominal. The Executive Control requires the statement SOL 144 to call for the Static Aeroelastic Response DMAP sequence, SOL 144. Optional case control entries are AESYMXZ and AESYMXY, which specify symmetry flight conditions (these can be alternatively entered using the AEROS entry if a single symmetry is being used in the analysis). The AECONFIG command designates a parameter that can be utilized by the database with AECONFIG=AEROSG2D the default. The AERCONFIG command is a required parameter when executing the flexible part of a rigid/flexible aeroelastic analysis.

The stability derivatives are obtained as part of the solution process and are always printed. All other derived quantities of interest must be requested in the Case Control: The subcase commands $\mathrm{APRES} = n$ and $\mathrm{AEROF} = n$ request the aerodynamic pressures and forces for a set of aerodynamic grid points defined by n. The flight conditions are specified for each SUBCASE on the required TRIM commands that invokes AELINK and TRIM (or TRIM2) entries.

The reference geometry for the dimensionless stability derivatives are specified on the AEROS entry. Three bulk data entries; viz., AESTAT, AESURF and AEPARM, can be used to define aerodynamic extra points used in the trim analysis. The AESTAT entry is used to invoke specific aerodynamic conditions with the LABEL field defining each, such as angle of attack (ANGLEA) or vertical acceleration (URDD3). The presence of this entry triggers the generation of a downwash vector that provides the aerodynamic force for the extra point. Trimming surfaces are specified on a AESURF entry and are used to define the aerodynamic boxes that make up the surface. Note that up to two sets of aerodynamic elements and hinge lines can be defined for a single AESURF, enabling; for example, specifying right and left elevators as a single control surface. There are a number of other optional parameters that can be input using the AESURF bulk data entry to support control surface effectiveness, reference dimensions and deflection and hinge moment limits.

If the aerodynamics for the control surface are associated with external aerodynamics, NOLDW is specified and the aerodynamic are input using some form of direct input, such as the AEFORCE entry. The AESURFS entry is a companion to the AESURF entry and can be used to specify structural grids whose mass can be used to derive the moments of inertia about the control surface hinge line. The AEPARM entry provides an additional means of specifying an aerodynamic extra point. In this case, you must supply not only the LABEL of the extra point but also any loading data associated with it. This entails the specification of bulk data entries including UXVEC, AEFORCE, AEDW, AEPRESS and DMIJ,DMIJI and DMIK. The UXVEC entry defines a state that can be any combination of the available extra points. This leads to a number of complexities, so the capability must be used with care. For a given trim analysis, the number of trim states is equal to the number of AESTAT,AESURF and AEPARM entries, but the total number of states is equal to the number of AESTAT,AESURF entries NOT mentioned on a UXVEC entry plus the number of relevant UXVEC entries. An important exception is when the UXVEC contains a LABELi corresponding to an AESTAT with UXi = 1.0 and either LABELj = INTERCPT with UXj = 1.0 or no INTERCPT. In this case the state is added to the existing one from the AESTAT. This can be used; e.g., to input aerodynamics on a fuselage that are not contained in the aerodynamic model. If the UXVEC contains a LABELi corresponding to an AESTAT and UXi is not equal to 1.0, it is an error.

The UXVEC entry defines the associated state while associated AEDW,AEPRESS,AEFORCE entries point to the user defined data for the state. Note that these three entries require a Mach number specification that corresponds with trim Mach number specified on the TRIM entry, a UXID that identifies the UXVEC state and a character label that points to the actual data. The AEDW and AEPRESS entries provide a way of specifying downwash and pressure data on the aerodynamic model. The AEDW points to DMIJ/DMIJI entries that specify downwash values at the j-set points of the model as specified in Figure 3-8 while the AEPRESS entry points to a DMIK entry with pressure values specified in the k-set as specified in Figure 3-7. The AEFORCE entry can point to the structural or the aerodynamic mesh as specified by the MESH describer (AERO or STRUCT). For AERO forces, an DMIK entry is invoked while the STRUCT option leads to a set of loads that can be any of the types of loads supported in a statics analysis. Care must be taken while interpreting the full vehicle integrated loads on aerodynamic monitor points when using UXVEC to specify AEFORCE with STRUCT loads. Since the forces affect the structural mesh directly, the breakdown of integrated loads into rigid, elastic and inertial portions for structural monitor points are from direct integration. However, since no aerodynamic mesh is specified using AEGRID, the integrated loads output for aerodynamic monitor points are not meaningful. There is a special case when there are no AESTAT entries and all the aerodynamics are input using AEPARM entries. In this case, it is necessary to establish the INTERCPT aerodynamics explicitly so that at least one UXVEC must have label INTERCPT=1.0, either explicitly or by default.

It is seen that the AEPARM entry enables considerably more flexibility in specifying a TRIM analysis relative to the more standard AESTAT/AESURF specifications. Notably, a nonlinear solution can be triggered by inputting data for a number of UXVEC entries that share the same set of extra point labels but with different settings. Care must be taken in the specification of the extra point labels used. When different settings of only a single extra point label are intended, accuracy in TRIM analysis is ensured by using an additional AEPARM extra point label fixed at the same setting for the various UXVEC listings. This ensures a smooth interpolation for the intended controller. This could be applied; for example, to provide input for a thruster at a range of gimbal angles. Use of AEPARM in Nonlinear Solutions illustrates this.

The AELINK bulk data entry enables the specification of any linear relationship among the aerodynamic extra points (AESTAT, AESURF or AEPARM entries). For example, the inboard and outboard ailerons could be linked together by a schedule specified by flight control engineers. The two trim entries differ in that TRIM entry requires the specification of all fixed variables, including the ones that are set to 0.0. Any variable that is not specified is considered to be free. Note that a valid trim specification requires

$$nr + nt + nael = nx \tag{3-2}$$

where,

nr	=	number of SUPORTed degrees of freedom
nt	=	number of constrained variables on the trim entry
nael	=	number of AELINK entries for this trim condition
nx	=	number of aerodynamic extra points (i.e. number of AESTAT, AESURF, AEPARM entries)

By contrast, the TRIM2 entry requires the specification of only non-zero fixed variables and the designation of the aerodynamic extra points that are free. Any aerodynamic extra point that is not otherwise specified in this case is assumed to be fixed at 0.0. This entry is useful; e.g., when there are many control surfaces that are undeflected in the trim state.

Both the TRIM and the TRIM2 entries support the AEQR parameter which governs how much aeroelastic feedback is included in the analysis. The default value of AEQR=1.0 provides for the full aeroelastic effect while values less than one multiply the dynamic pressure of the feedback to result in a smaller correction.

The TRIMF case control command enables the output of trimmed forces to the MSC Nastran punch file (or other user specified location) in the form of FORCE and MOMENT bulk data entries. Considerable flexibility is provided in this output with a default printout of the total elastic forces and options for the additional print of rigid and flexible inertial, applied, aerodynamic and total loads.

Main Index

Stability derivatives are typically computed about the zero state of all the aerodynamic analysis. If the analysis is linear, this is sufficient. For nonlinear analyses, the AEUXREF case control command can be used to specify the computation of stability derivatives about the trim state or about a state specified by a UXVEC entry invoked by the AEUXREF case control command.

Correction Factors

Equations (2-104) and (2-105) contain terms that provide you with the ability to modify the internally generated aerodynamics. The first of these is a user input downwash vector $\left\{ w_j^g \right\}$ that can account for terms such as lifting surface incidence, camber and twist. This is input as a direct matrix input with the explicit name of W2GJ (that is, any other name will be ignored). This is a single vector that applies to all subcases in the static analysis. The direct matrix input can be input using the general DMI form or the special purpose DMIJ bulk data entry. The two forms are equivalent, but the DMIJ form may be somewhat easier to input since the data are entered as a function of box ID rather than row number. Note that the data are entered in the js-set for the DMIJ entry allowing for generality in the aerodynamic input whereas the DMI input is in the j-set. For the doublet-lattice method with interference bodies, the direct matrix input is entered using the DMIJI or the DMI entry.

The second correction term is $\left\{ f_j^e \right\}$ and supports input of user defined pressures that may come from wind tunnel or other aerodynamic analysis. These data use the restricted name FA2J and can be input on a DMIK or DMI entry. As in W2GJ, the use of the DMIK may be slightly easier to prepare since data are entered in terms of the boxid and not dof in the k-set. Similar to W2GJ, DMIK data for FA2J are entered in the ks-set while DMI data can be entered in the k-set.

Finally, the weight matrix term shown as $[W_{kk}]$ in (2-105) is entered using the restricted name of WKK (or WTFACT). This is a square matrix that can be entered using DMIK or DMI.

External Aerodynamics

The previous subsections have described the aerodynamics available in MSC Nastran where the aerodynamic operators are developed internally based on user supplied geometry and flight condition information. As the name implies, External Aerodynamics, are those derived outside of MSC Nastran and input into the code using a special purpose user interface. An obvious application of this capability would be to input results from a computational fluid dynamics (CFD) code that can supply high-fidelity aerodynamics that can capture, for example, nonlinear effects that are not available with the internal panels methods. Other applications could use aerodynamic available from tests.

The aerodynamic mesh for external aerodynamics is entered using a combination of AEGRID, AEQUAD4 and AETRIA3 bulk data entries. The user has complete freedom in specifying the mesh so there are no restrictions to flat panels or streamwise coordinates. For a CFD model, the mesh will typically be the wetted surface of the air vehicle. Each aerodynamic grid point has 6 dofs in the ks or js set. The j and k sets corresponding to these points have 3 dofs per AEGRID.

The AEPARM entry described above is used to specify the associated aerodynamic extra points. The AESURF entry can be used as well with the if the LDW describer is set to NODLW, indicating that the user must input the terms that lead to the forces for this control surface. The AESTAT entry can be used as well if this does not create a conflict between internal and external aerodynamics, but the preferred solution is to use the AEPARM entry for all non-control surface loads. For a particular subcase, AEFORCE or AEPRESS entries the M(ach) describer matching the one specified on the TRIM and symmetry inputs for the subcase can be used to drive the input of aerodynamic forces or pressures, respectively (The AEDW entry is not supported for external aerodynamics). The AEPRESS entry, in turn, specifies a UXVEC entry that identifies the state for the load and a DMIJ entry that supplies the actual pressures at the AEGRID locations. The AEFORCE entry also specifies a UXVEC entry and can then either request a static load or an aerodynamic load via the MESH describer. For MESH = STRUCT, the LSET on the entry identifies a load set that can be composed of any load type (e.g., FORCE, MOMENT, etc.) available for static loads. For MESH=AERO, the DMIK describer points to a DMIK entry that defines the aero loading.

The UXVEC entry has an in ID that is referenced by an AEFORCE or AEPRESS entry and then refers so a state made up of available extra points and their values. It is seen that by allowing for multiple UXVEC's in a given trim task, the ability to support nonlinear aerodynamics has been introduced. For example, the UXVEC could provide a sweep of angles of attack derived from separate CFD analyses at the given states.

Aerodynamic pressures or forces are entered at the aerodynamic grid points and can be in displacement degree of freedom. It should be reiterated that the js set and ks sets are identical in this paradigm but due to legacy considerations, pressures are entered in the js set while forces are input in the ks set.

It should be clear that the external aerodynamics capability of this sections requires significant data preparation on the part of the user with limited commercial software available to assist in its preparation. It is recommended that investigators interested in pursuing this capability devote some effort into the automation of preparing these inputs. MSC can assist in providing guidance and candidate solutions for transitioning data from an external source into the MSC Nastran paradigm described here.

A final comment is that the nature of the external aerodynamics motivates the provision for splining with curved surfaces as addressed in the Interpolation from Structural to Aerodynamic Models of this guide. The SPLINE4-7 methods all support an aerodynamic model that has a curved surface.

Rigid/Flexible Aerodynamics

The external aerodynamics of the previous section provide a means of incorporating high-fidelity aerodynamics into an aeroelastic analysis. A feature that is lacking from this solution is the aerodynamic feedback wherein the deformations resulting from the aerodynamics alter the aerodynamics. On the other hand, the internal aerodynamic methods, such as the doublet lattice method, have a built in AIC (aerodynamic influence coefficient) matrix which does provide this feedback. MSC provides a hybrid solution that allows the combination of the higher order aerodynamics supplying the loads with the AIC of a panel method supplying the aeroelastic feedback. It is felt that the linear correction provides an improved aeroelastic solution.

The implementation of the methodology, which is referred to as Rigid/Flexible Aerodynamics requires separate runs to provide rigid aerodynamics and the flexible aerodynamics since both models cannot co-exist for the same air vehicle. Instead, a preliminary run is made using the external aerodynamics of the previous subsection and a second run is made using the Restarts capability to combine the external aerodynamic database with the internal aeroelastic corrections. An example is provided in Chapter 7, while the basic methodology is explained here. The external aerodynamic model provides the aero mesh using AEGRID, AEQUAD4 and AETRIA3 entries. The loads are input using the AEPARM, UXVEC, AEFORCE, AEPRESS, DMIJ, DMIK entries as described above. The AECONFIG case control parameter is used to specify the datablocks that are associated with the external aerodynamics, so this is a required command for the "Rigid" run.

For the second run, the flexible corrections are derived from the internal aerodynamics model using CAERO1 entries. Case control contains an AERCONFIG command that identifies the rigid database of the previous run. The AECONFIG command is optional (AEROGSD is the default) and qualifies the datablocks associated with the flexible model. Both models need the same number of aerodynamic extra points and the names of the aerodynamic extra points need to be the same. AESTAT or AEPARM can be used in the rigid run to identify the extra points associated with reserved names on the AESTAT entry such as ANGLEA. The structural portions of the two models must be identical.

CSV Output of Static Aeroelastic Results

Two CSV (comma separated values) files are available to provide a summary of static aeroelastic results that would otherwise have to be gleaned from disparate parts of the .f06 file. This is particularly valuable when hundreds of subcases are being analyzed in a single run. The intent is that these files can be viewed and manipulated in a spreadsheet application.

LDSUM

PARAM LDSUM (see Chapter 6 in the *MSC Nastran Quick Reference Guide*) can be placed in case control or the bulk data packet to activate the output of critical results for each subcase. These results include subcase id, Mach and dynamic pressure value, trim configuration, mass and CG information and monitor point results that are controlled by the value of LDSUM as explained in the QRG. The unit of the CSV file is specified by PARAM XYUNIT and an assign statement such as:

```
assign userfile='aecsv1.csv' status=unknown form=formatted unit=52
```

defines the file where the results are stored. The unit 52 corresponds to PARAM XYUNIT 52. The first row in the spreadsheet provides titles for the columns that contain the results. Each subsequent row contains the requested results for a single subcase. PARAM XYUNIT is also used in SOL 200 (see *MSC Nastran Design Sensitivity and Optimization User's Guide*) to provide design optimization results. If the SOL 200 run includes static aeroelastic subcases and PARAM LDSUM is used, the resulting spreadsheet will have a row for each static aero subcase for each design iteration followed by design optimization results.

SDCSV

PARAM SDCSV (see Chapter 6 in the *MSC Nastran Quick Reference Guide*) can be placed in case control or the bulk data packet to activate the output of stability derivatives for each subcase. As shown in the QRG, the user can select up to 6 forms for each stability derivative. For each row of the output, the stability derivative data is preceded by subcase id, Mach and dynamic pressure value, trim configuration, and mass and CG information The unit of the CSV file is specified by PARAM SDUNIT and an assign statement such as:

```
assign userfile='aecsv2.csv' status=unknown form=formatted unit=51
```

defines the file where the results are stored. The unit 51 corresponds to PARAM SDUNIT 51. The first row in the spreadsheet provides titles for the columns that contain the results. Each subsequent row contains the requested results for a single subcase.

Divergence Analysis

The Static Aeroelastic Solution Sequence can also perform a divergence analysis. The analysis is invoked by a `DIVERG` command in Case Control which, in turn, invokes a `DIVERG` Bulk Data entry. The eigenanalysis of (2-145) is carried out using a complex eigensolver.

- A `CMETHOD` Case Control command invokes an EIGC Bulk Data entry that specifies the attributes for the eigenanalysis. The `CMETHOD` request invokes a complex Lanczos eigenanalysis that asks for five roots to be extracted.
- The `DIVERG` Bulk Data entry allows the user to extract a desired number of divergence pressures (typically one, since the second and higher pressures are not of practical interest) for the Mach numbers given on the entry.

  The `DIVERG` Bulk Data entry indicates that the analysis is to be performed using incompressible aerodynamics ($m = 0.0$) and that five divergence roots are requested. Results from executing this input file are given at the end of Static Aeroelasticity in lieu of an example in Static Aeroelastic Analysis Problems.

Sample Case Control commands and Bulk Data entries for a divergence analysis are given in Listing 3-1.

Listing 3-1 Divergence Analysis Sample

```
TITLE = EXAMPLE HA144B:  BAH JET TRANSPORT WING DYNAMIC ANALYSIS
SUBTI = DIVERGENCE ANALYSIS
  ECHO = BOTH
  SPC = 13 $
  MPC = 1 $ CONTROL SURFACE RELATIVE MOTION
  SET 2 = 7 THRU 12
  SET 3 = 11
  DISP = 2
  SPCF = 3
  AEROF = ALL
  APRES = ALL
  DIVERG = 100
  CMETHOD = 100
BEGIN BULK
.
.
.
DIVERG     100      5        0.0
EIGC       100      CLAN     MAX                          5
$
ENDDATA
```

Flutter Analysis

A flutter analysis determines the dynamic stability of an aeroelastic system. As noted in Overview of Aeroelastic Analysis, 8, three methods of analysis are available: the American (K) method, a restricted but more efficient American (KE) method, and the British (PK) method. There are variation to the PK method that provide *no-looping* and a *sweep* (as opposed to iterative) solution.

The British method not only determines stability boundaries but provides approximate, but realistic, estimates of system damping at subcritical speeds that can be used to monitor flight flutter tests. The system damping obtained from the K- and KE-methods is a mathematical quantity not easily related to the physical system damping. As with static aeroelastic analysis, flutter analysis presupposes a structural model, an aerodynamic model, and their interconnection by splines.

The modal technique is used to reduce the number of degrees of freedom in the stability analysis. It should be appreciated by the user that the use of vibration modes for this purpose constitutes a series solution, and that a sufficient number of modes must be used to obtain convergence to the required accuracy. An aspect of the modal method is a transformation of the aerodynamic influence coefficients into modal coordinates. For computational efficiency, this transformation is carried out explicitly for only a few Mach numbers (m) and reduced frequencies (k). These generalized (modal) aerodynamic force coefficient matrices are then interpolated to any additional Mach numbers and reduced frequencies required by the flutter analysis. Matrix interpolation is an automatic feature of the program. The MKAERO1 and MKAERO2 Bulk Data entries allow the selection of parameters for the explicit calculations of the aerodynamic matrices.

Because of the iterative nature of the PK-method, the manner of convergence is frequently of interest to the user and can be seen by specifying the diagnostic, DIAG 39, in the Executive Control Section.

The Case Control selects the flutter method on the FMETHOD command. It also selects the real eigenvalue method on a METHOD command for use in finding the vibration modes and frequencies for the modal flutter analysis. If the K-method of flutter analysis is to be used, a CMETHOD command is also required to specify the complex eigenvalue method. Plot requests may also be made in the Case Control for the frequency and damping versus velocity curves. Features of the flutter methods are shown in Table 3-2

Table 3-2 Flutter Analysis Methods

Feature	Method		
	K	KE	PK Basic
Structural Matrices	K (complex)	K (complex)	K (real)
	B (complex)		B (real)
	M (complex)	M (complex)	M (real)
Aerodynamic Matrices	M (complex)	M (complex)	K (real)
			B (real)
User Input Loops	ρ -Density	ρ -Density	ρ -Density
	m-Mach Number	m-Mach Number	m-Mach Number
	k-Reduced Frequency	k-Reduced Frequency	V-Velocity
Output	V-g Curve	V-g Curve	V-g Curve
	Complex Modes		Complex Modes
	Displacements		Displacements
	Deformed Plots		Deformed Plots
Method	Compute Roots for User Input ρ, m, k	Compute Roots for User Input ρ, m, k. Reorder Output so a “Curve” Refers to a Mode.	See Table 3-3b
Eigenvalue Method	Several Methods Available, Selected by User via CMETHOD in Case Control	QZ algorithm*	QZ algorithm*

* No CMETHOD entry is used. If NASTRAN system cell 108 is set to 1, the Real Upper Hessenberg Method is used for eigenanalysis. This latter method requires a non-singular mass matrix while the QZ algorithm does not. Moler and Stewart [Reference 34].

All methods (except PKNL and PKNLS) allow looping through three sets of parameters: density ratio ρ/ρ_{ref} (ρ_{ref} is given on an AERO data entry), Mach number m, and reduced frequency k or velocity.

For example, if you specify one value of density and two values of two values of Mach and reduced frequency or velocity, there will be four analyses in the following order:

Table 3-3 Looping for K,KE,PK and PKS Methods

LOOP (CURVE)	DENS	MACH	RFREQ or VELOCITY
1	1	1	1
2	1	1	1
3	1	2	1
4	1	2	2

For the PKNL and PKNLS methods, there is no looping and you must enter equal number of densities, Machs and velocities. In this way, input can be prepared in a way so that the triplets match an actual point in the atmosphere. In this case, if you specify three densities, three Mach number and three velocities, there are three loops as shown in Table 3-4.

Table 3-4 Looping for PKNL and PKNLS Methods

LOOP (CURVE)	DENS	MACH	RFREQ or VELOCITY
1	1	1	1
2	2	2	2
3	3	3	3

K-Method

The K-method of flutter analysis considers the aerodynamic loads as complex masses, and the flutter analysis becomes a vibration analysis using complex arithmetic to determine the frequencies and artificial dampings required to sustain the assumed harmonic motion. This is the reason the solution damping is not physical.

When a B matrix is present, complex conjugate pairs of roots are no longer produced. MSC Nastran uses the `CEAD` module to extract all requested roots but only selects roots with a positive imaginary part for the flutter summary output. Values for the parameters are listed on FLFACT Bulk Data entries.

Note:	If a large number of loops are specified, they may take an excessive time to execute. Multiple subcases can be specified to pinpoint particular regions for study while controlling CPU resources.

KE-Method

The KE-method is similar to the K-method. By restricting the functionality, the KE-method is a more efficient K-method. The two major restrictions are as follows:

- No damping (B) matrix is allowed.
- No eigenvector recovery is made.

A complex stiffness matrix can be used to include the effects of structural damping. The KE-method therefore cannot consider control systems in which damping terms are usually essential, but it is a good method for producing a large number of points for the classical V-g curve of a system without automatic controls.

The KE-method also sorts the data for plotting. A plot request for one curve gives all of the reduced frequencies for a mode whereas a similar request in the K-method gives all of the modes at one k value. Use of the alternative method for the specification of k (see the FLFACT Bulk Data entry) is designed to produce well-behaved V-g curves for the KE-method.

As discussed in Dynamic Aeroelastic Analysis, the K- and KE-methods of flutter analysis allows you to select a linear spline that interpolates on reduced frequency for aerodynamic matrices at the Mach number closest to the required Mach number, or a surface spline that interpolates on both Mach number and reduced frequency. It is recommended that the linear spline be used in most cases.

PK-Method

The PK-methods treats the aerodynamic matrices as real frequency dependent springs and dampers.

- For the iterative methods (PK and PKNL) a frequency is estimated, and the eigenvalues are found. From an eigenvalue, a new frequency is found.
- For the sweep method (PKS and PKNLS), roots are found by sweeping through the range of applicable k-values.

Advantages of the PK methods are as follows:

- They permit control systems analysis.
- The damping values obtained at subcritical flutter conditions appear to be more representative of the physical damping.
- When the stability at a specified velocity is required since many fewer eigenvalue analyses are needed to find the behavior at one velocity.

Identification of the aerodynamic configuration is given by the `AECONFIG` case control command while `AESYMXY` and `AESYMXZ` commands can be given to provided symmetry information. The flight condition and remaining flutter control specifications are in the Bulk Data input. The `AERO` entry gives the basic aerodynamic data (allowing for symmetry conditions is case control commands have not been specified). The `MKAERO1` or `MKAERO2` entries specify the Mach number and reduced frequencies for which the generalized aerodynamic forces are computed explicitly. The `FLUTTER` entry selects the method of flutter analysis and refers to `FLFACT` entries for density ratios, Mach numbers, and reduced frequencies (K- and KE-methods) or velocities (PK-method). The `IMETH` field on the `FLUTTER` entry specifies the aerodynamic interpolation method.

The PK-methods supports only the linear spline method or a cubic spline interpolation method can be used. The EIGR entry selects the real eigenvalue method to obtain the vibration modes and frequencies. If the K-method of flutter analysis is to be used, an `EIGC` entry selects the complex eigenvalue method to obtain the flutter roots and modes. The number of vibration modes computed is specified on the EIGR entry, but the number needed in the flutter analysis should be determined by a convergence study. The parameters `LMODES` or LFREQ and HFREQ can be used to select the number of vibration modes to be used in the flutter analysis and can be varied to determine the accuracy of convergence. The NVALUE field on the FLUTTER entry can be used to limit Flutter Summary output. Finally, the parameter PARAM,VREF may be used to scale the output velocity. This can be used to convert from consistent units (for example, in/sec.) to any units the user may desire (for example, knots) as determined from $V_{out} = V/(VREF)$.

If physical output (grid point deflections or element forces, plots, etc.) is desired these data can be recovered by using a Case Control command; for example, the physical displacements can be obtained with the DISPLACEMENT case control command, DISP = ALL. A selected subset of the cases can be obtained by the OFREQUENCY command. The selection is based upon the imaginary part of the eigenvalue: velocity in the K- or KE-method, frequency in the PK-method.

Example problems that demonstrate the different methods of flutter analysis with the various aerodynamic theories are presented in Flutter Analysis Problems.

Dynamic Aeroelastic Response Analysis

The purpose of dynamic aeroelastic response analysis is to study the reactions of an aeroelastic system to prescribed loads and displacements, and to atmospheric gust fields. The effects of a control system can also be assessed if its equations (transfer functions) have been included in the (aeroservoelastic) model. As in flutter analysis, the modal method is employed to reduce the computational effort. SOL 146 can solve for frequency response, random response, and transient response problems in the presence of an airstream. Examples of response problems in which aerodynamic effects should usually not be neglected include high speed landing loads, in-flight store ejection loads, and loads and accelerations in a gust field.

The analyses of frequency response, random response, and transient response without aerodynamic effects are discussed in the *MSC Nastran Basic Dynamic Analysis User's Guide*. That guide should be consulted as a reference for the frequency response and random response analyses considered here. However, it only discusses transient response analysis by direct integration methods, whereas Fourier transform methods are employed in SOL 146 for aeroelastic response because the unsteady aerodynamic loads are calculated only in the frequency domain.

MSC Nastran utilizes several techniques in solving for the response to an enforced displacement: one is the large mass method, and the other is the Lagrange multiplier method while a third uses explict enforced displacements. All three methods are discussed in the *MSC Nastran Dynamic Analysis User's Guide.* The Lagrange multiplier method requires less judgment and is computationally efficient with a small number of modes, so it is utilized effectively in some dynamic aeroelastic response analyses.

The implementation in the Bulk Data Input for the various selections in the Case Control Section is illustrated in the example problems of Dynamic Aeroelastic Response Analysis.

Frequency Response Analysis

A frequency response analysis is an integral part of random response analysis and transient analysis, and it can be of interest in its own right to obtain transfer functions for designing control systems. If only the frequency response is desired, you must specify the frequency content of the loading via the RLOADi Bulk Data entry.

If the loading is more conveniently specified in the time domain, specifically, on the `TLOADi` Bulk Data entry, the solution sequence will lead to the transient response.

The input data for a dynamic aeroelastic response analysis are similar to those required for a flutter analysis. The Executive Control Section will include the SOL 146 command for the Dynamic Aeroelastic Response sequence.

Case Control Commands

The Case Control is used to select constraints, methods, and output. The `METHOD` command is required since it selects a method to compute the structural modes and frequencies that provide the modal basis for the response analysis. Some form of modal damping should be requested [see discussion of alternative representations of damping in Reasons to Compute Normal Modes (p. 41) in the *MSC Nastran Dynamic Analysis User's Guide* since all structures have some damping which can affect the results significantly. The complex structural damping can be used here since it is consistent with the harmonic assumptions of a frequency response analysis. A frequency selection FREQ is required, and some form of excitation, either loading (for example, direct loads, `DLOAD`), enforced displacement or a gust field (for example, `GUST` Case Control command) is required. Output that can be requested includes the solution set displacements (amplitudes of modes and extra points), physical displacements (grid points and extra points), constraint forces and aerodynamic loading, element forces and stresses, and plots.

The user specifies the flight conditions in the Bulk Data Input. The same velocity is specified on both the `AERO` and the `GUST` data entries if a gust response is desired, while Mach number and dynamic pressure are supplied on the Bulk Data entries `PARAM,MACH` and `PARAM,Q`. The `FREQi` entry defines the set of frequencies for which the frequency response is performed.

Random Response Analysis

For a random response analysis, the loading is specified in the frequency domain on the DLOAD Case Control command in conjunction with RLOADi entries, by an enforced motion or by a GUST command. To proceed with the random response analysis subsequent to the frequency response analysis, it is only necessary to specify the power spectral density of the excitation. A prescribed random loading is obtained by using the RANDOM Case Control command in conjunction with the RANDPS and TABRND1 Bulk Data entries that specify the input excitation power spectrum. For gust loading, the GUST Bulk Data entry points to either the von Karman or Dryden spectrum on the TABRNDG Bulk Data entry or a tabulated power spectrum that is input via the TABRND1 Bulk Data entry. The output power spectral density is requested by the XYOUT plot commands in Case Control. The root mean square values of each selected output response and its expected frequency, N_0, are automatically printed when output power spectra are requested.

Transient Response Analysis

For transient response analysis under a prescribed loading condition, the loading is specified on the `DLOAD` Case Control command in conjunction with `TLOADi` entries or by an enforced displacement. To proceed with the transient response analysis subsequent to the frequency response analysis, it is only necessary to specify the time history of the excitation. For a prescribed excitation, its time history is specified on a TLOADi entry. The output times are specified by the TSTEP Case Control command and Bulk Data entry.

For transient response to a gust, the GUST Case Control command invokes a GUST Bulk Data entry which in turns points to a TLOADi entry that gives the gust profile. The Bulk Data entry PARAM,GUSTAERO,-1 is necessary to generate the airloads required for the gust load calculation. On a restart; the default value (+1) is recommended if no new gust loads are to be computed. It Is also recommended that the gust aerodynamics be calculated once (that is, include PARAM,GUSTAERO,-1) in the initial aeroelastic solution (SOL 145 or SOL 146), so that all aerodynamics will be available on the database for a restart in SOL 146.

Aeroelastic Design Sensitivity and Optimization

The Design Sensitivity and Optimization User's Guide contains a comprehensive description of the MSC Nastran design sensitivity and optimization capability. This section contains supplementary information on the aeroelastic aspects of this capability and is divided into subsections on analysis, response evaluation, sensitivity, and optimization.

Multidisciplinary Analysis

For an optimization procedure to be of maximum benefit, it must be able to simultaneously take into account all the conditions that impact the design. For this reason, the design sensitivity and optimization capability in MSC Nastran is based on a multidisciplinary analysis capability that includes statics, normal modes, buckling, direct and modal frequency, modal transient, direct and modal complex eigenanalysis, static aeroelastic, and flutter analyses.

The static aeroelastic and flutter analysis capabilities present in the multidisciplinary analysis and design solution sequence (SOL 200) contain the full capabilities of the static aeroelastic (SOL 144) and flutter (SOL 145) solution sequences. It is necessary in SOL 200 to designate the type of analysis being performed for each subcase using the ANALYSIS Case Control command.

- ANALYSIS = SAERO is used for static aeroelasticity
- ANALYSIS = FLUTTER is used for flutter analysis.

Response Evaluation

For a sensitivity value to be computed, the user must designate it on a DRESP1 entry and either constrain it on a DCONSTR entry or identify it as the design objective using the DESOBJ Case Control command. Further, the DCONSTR set must be selected by either a DESSUB or a DESGLB Case Control command. For static aeroelasticity, the DRESP1 entry can be used to invoke standard static analysis responses, specifically, RTYPE = DISP, STRAIN, STRESS, FORCE, CSTRAIN, CSTRESS, and/or CFAILURE, as well as two responses, RTYPE = STABDER and/or TRIM, that are unique to static aeroelasticity.

The STABDER response requests a stability derivative response and therefore selects one of the components of an AESTAT or AESURF aerodynamic extra point. The selected response type can correspond to a restrained or unrestrained derivative (see Static Aeroelasticity), based on the value of the ATTB field. The utility of this request is that it is possible to determine how a key aeroelastic parameter, such as lift curve slope, C_{L_α}, varies when a structural change is made. More significant perhaps, it is possible to include design requirements on these stability derivatives in a MSC Nastran design optimization study.

The TRIM response on the DRESP1 entry requests a particular aerodynamic extra point by referencing an AESTAT or AESURF entry ID. The associated response is the magnitude of the aerodynamic extra point for the maneuver condition defined for the subcase. It is to be expected that the sensitivity of this response to a particular structural parameter is small. The response can have utility in limiting the range over which an aerodynamic value can vary during an optimization task; for example, by limiting an elevator rotation to be less than 20 degrees, therefore, unrealistic designs can be precluded.

A final DRESP1 response type related to aeroelasticity is for flutter (RTYPE = FLUTTER). The entry selects damping values from an aerodynamic flutter analysis as response quantities. The ATTi (i = 1,2,3 and 4) fields of this entry allow for a precise selection of the damping values from the available responses; that is, ATT1 specifies a SET1 entry that selects the mode set, ATT2 specifies an FLFACT entry that selects the set of densities, ATT3 specifies an FLFACT entry that selects a set of Mach numbers, and ATT4 specifies an FLFACT entry that specifies a list of velocities.

The requested data must exist from the analysis at precisely the Mach number, density, and velocity triplets specified by the FLFACT data. The effective use of this capability requires knowledge of the flutter characteristics of the vehicle so that the subset of the analysis results that are selected for design are both reasonable and comprehensive. For example, it would make little sense to try and alter the structure to modify undesirable damping values that result from the rigid body response of the vehicle. Similarly, most damping values are noncritical and can be safely excluded from the design task.

MSC Nastran can also construct synthetic responses that can be a function of DRESP1 response values, design variables values, user-defined constants, and grid locations. This is done using a combination of the DRESP2 entry to define the quantities that contribute to the synthetic response and a DEQATN entry that provides the equation that defines the synthetic response. A particular aeroelastic application of this capability is the construction of a response that predicts the roll performance of the vehicle as a function of the ratio of two stability derivatives:

$$\frac{pb}{2V\delta_a} = -\frac{C_{l_{\delta_a}}}{C_{l_p}}$$

Obtaining adequate roll performance is often a design driver for air-combat vehicles and typically entails enhancing the torsional stiffness of a wing. By use of the above relationship, this requirement can be incorporated into a MSC Nastran design task. An example of this is given in Aeroelastic Design Sensitivities of FSW Airplane (Example HA200A).

Sensitivity Analysis

The specification of response quantities as described in the preceding subsection is a means towards the end of obtaining information for the structural design task. The first type of information that is available is sensitivity results wherein the rate of change of a particular response quantity r_j, with respect to a change in a design variable x_j, is produced:

$$\lambda_{ij} = \partial r_i / \partial x_j$$

The The Design Model in the *Design Sensitivity and Optimization User's Guide* contains a detailed description of design sensitivity analysis while in this Aeroelastic Design Sensitivities and Optimization provides a description of the calculations required to provide these sensitivities for aeroelastic responses. This section provides guidelines useful in obtaining desired sensitivity information.

The user selects sensitivity analysis by setting PARAM,OPTEXIT equal to 4. An example of the output obtained with this option is given in Aeroelastic Design Sensitivities of FSW Airplane (Example HA200A).

The MSC Nastran implementation of design sensitivity analysis requires that the responses specified on DRESP1 and DRESP2 entries must be constrained in order for design sensitivity to occur. Further, the constrained responses have to pass through screening criteria that are applied in MSC Nastran in order to limit the number of responses that are used in a design sensitivity and/or optimization task. The constraint specification begins with a `DESSUB` Case Control command that identifies the constraint set that is to be applied to a particular subcase.

The command invokes `DCONADD` and/or `DCONSTR` Bulk Data entries, where `the` optional DCONADD entry is used to collect DCONSTR sets applicable in the subcase and the `DCONSTR` entry selects the `DRESPi` entries and specifies lower and upper limits on the response value. The screening procedure selects the constraints that are greater than a threshold value with a further limitation that only a limited number of responses of a given type will be retained. The user can force a response to be retained by using the `DSCREEN` Bulk Data entry to reduce the threshold value and/or increase the number of retained responses. For sensitivity analysis, a trick that can be used to force the retention of a response is to specify identical upper and lower limits on the `DCONSTR` entry associated with the response.

Optimization

Once the user has specified the design variables, a design objective, and design constraints, MSC Nastran can be used to determine the design that provides the minimum (or maximum) value of the objective while satisfying the imposed constraints. This is a powerful tool for the aeroelastician in that it provides a systematic means of finding an improved design. It can also be appreciated that, particularly in the context of aeroelasticity, the user must be involved with the optimization task and apply reasonableness tests to the designs that are achieved. An optimization task exploits any deficiencies in the analysis in a way that helps it achieve its goals. For guidelines into performing optimization tasks, including means of gaining insight into the performance of the optimizer, refer to Design Sensitivity and Optimization User's Guide.

One user guideline that is relevant here is that the use of 0.0 as a limiting value on the DCONSTR entry should be avoided, if possible. MSC Nastran uses a normalized value for the constraint that entails dividing the response value by the constraint limit. Specifying a limit of 0.0 then produces a division-by-zero problem that MSC Nastran avoids by substituting a small number for the limit. In the context of aeroelasticity, the user would be inclined to apply an upper bound of 0.0 to a DRESP1 entry that has an RTYPE of FLUTTER. This would ensure a negative damping level. It is recommended that a DRESP2 entry be used to offset the flutter response from zero and also to scale the response so that the constraint varies over a wider range than the unscaled response.

The `DRESP2` response is of the form:

$$R_2 = \frac{\gamma - OFFSET}{GFACT}$$

where γ is the flutter response, OFFSET is the offset value (typically 0.3) and GFACT is the scaling factor (typically 0.1). The DCONSTR entry would then impose an upper bound limit of -OFFSET/GFACT on the DRESP2 response, and this would be equivalent to restricting the flutter damping value to be negative.

Monitor Points

"Monitor Points" is a concept originally developed for static aeroelasticity but has since been applied in the solution sequences 101,103,105,108,109,111,112,144,146 and 200. They are basically postprocessing operators that allow for the monitoring of key results in an analysis that is beyond what is available in standard data recovery. This section provides an overview of the available monitor point types and examples are each are shown in the results of Chapters 7 and 9.

The MSC Nastran user interface for Monitor Points starts with the MONITOR (Case) Case Control command, which provides control over the printing of the monitor points results. Toggles can be used to control the print of the individual monitor types. This command must be placed above the subcase level or in the first subcase and applies to all subcases.

- MONPNT1 - The MONPNT1 entry provides integrated loads at a user defined point in a user defined coordinate system that are output in a user defined output coordinate system. The user also identifies the nodes (on either the structural or the aerodynamic model) whose loads are to be integrated. This enables the output of the applied loading for the specified set of nodes and can be used; e.g., for the batch calculation of VMT (shear moment and torque) data.
- MONPNT2 - The MONPNT2 entry provides element results from the TABLEs Stress, Strain, or Force in a tabulated fashion. This can be used to pinpoint a particular response for output, as opposed to finding a particular item in a large OFP listing. For the results to be accurate, the term selected must be a linear function of the displacements.

  The user must identify the element TYPE and NDDL item. The type and nddl item is obtained from the nddl description for each table. See QRG Remark 5 of this entry. There are separate types for composite and element corner results.
- MONPNT3 - The MONPNT3 entry provides a summation of grid point forces at user specified integration points and in a user defined coordinate system. The summation of the internal loads is useful in calculating resultant forces at a cut in the structure. This can be used to provide the net load acting at a fuselage or wing station by making a "cut" in the structure and then identifying all the grids and elements on one side of the cut.

  The entry NAME is identified with a piece of structure by listing the elements and nodes associated with it. The grid point force data associated with these entities is then integrated to the location specified on the entry. The XFLAG can be used to exclude certain grid point force types from consideration.

- MONDSP1 - The MONDSP1 entry allows for the sampling of a displacement vector to create a blended displacement response at a user specified point and coordinate system. The displacement monitor point is essentially an RBE3 element (limited to a single dependent point) and the dependent grid is now an arbitrary point. The averaged displacement can be seen as providing a qualitative assessment of the elastic deflection of a vehicle. An example is to monitor the nominal pitch and plunge at a station along the wing.

  This entry is similar to the MONPNT1 entry but now it is displacements that are being averaged. As with the MONPNT1, the COMP field, points to a AECOMP entry which specifies a SET1 entry or entries (or AELIST for aerodynamic boxes) that specify the grids to be monitored.

- MONSUM - The MONSUM entry defines a new monitor result that is the weighted sum of existing monitor results. The existing monitor points do not need to be of the same type but they must be of similar type.

  This entry can be used for both updating and summing of monitor point results. It allows for the modification of existing component results from MONDSP1, MONPNT1 and MONPNT3. A scalar multiple, for example, can provide a change in sign or a change in units. Enabling the weighted summation or two or more MONDSP1, MONPNT1 or MONPNT3's, that are of the same type, can provide the ability to present running results along a wing or fuselage. Note that a differentiation is made between aerodynamic (AEMONDSP1 and AEMONPNT1) and structural (SMONDSP1 and SMONPNT1) monitor points. AEMONDSP1 and SMONDSP1 are of the same type and can be summed. Similarly, AEMONPNT1 and SMONPNT1 are of the same type. There are numerous comments in the QRG for the MONSUM (and all monitor point entries) and you should study these carefully to understand and appreciate their features.

- MONSUM1 - The MONSUM1 Bulk data entry specifies the location of the summed quantity. This enables the summation of monitor points from disparate points to a single location.

  The first continuation defines a CP,X,Y,Z, CD combination that specifies the point where the summation is said to occur and performs the summation using the equation provided below. By contrast, the MONSUM does not specify the location and therefore cannot be used in subsequent MONSUMT processing.

  The MONSUM1 does not support the combination of MONDSP1's since no physically meaningful interpretation or application can be envisioned for combining MONDSP1's in this manner.

  The underlying equation that is executed for the MONSUM1 is:

$$MONSUM1_j = \sum_i^n COEF_{ij} MR_i$$

  Where MR_i is the result from the individual component.

  Relative to the MONSUM, the MONSUM1 allows the user to specify where the summed output is requested. MSC Nastran uses this information plus the locations of the referenced monitor points that are being summed to perform a coordinate transformation as part of the summation.

- MONSUMT - The MONSUMT Bulk data entry provides the ability to transfer moments and thereby allows the specification of a monitor point location that is apart from the finite element model. This facilitates communication between the loads group and the stress group in the development/simulation process.

  With the MONSUMT entry moment transfers do occur. The first continuation defines a CP,X,Y,Z, CD combination that specifies the point where the loads are to be monitored and performs the summation/transfer using the equation provided below. By contrast, the MONSUM1 location is user specified and does not involve moment transfer.

  The MONSUMT like MONSUM1 does not support the combination of MONDSP1's since no physically meaningful interpretation or application can be envisioned for combining MONDSP1's in this manner.

  The MONSUMT can reference the results of another MONSUMT or MONSUM1 as long as there is not a circular reference.

  The underlying equation that is executed for the MONSUMT is:

$$MONSUMT_j = \sum_i^n T_{ji} MR_i$$

  Where T_{ij} is a partial rigid body vector for the location of the monitor points being summed and MR_i is the result from the individual component.

- MONCNCM - The MONCNCM entry is a special purpose monitor point that is restricted to SOL 144 and CAERO1 entries. It provides stripwise aerodynamic lift and pitching moment results. Similar results could be extracted using the MONPNT1 entry, but the MONCNCM entry provides a simple user interface that could help in visualizing the aerodynamics and aid in generating corrections factors. The code internally determines if flat plate panels are abutting in the streamwise direction and, if they are, considers this a single strip from the leading to the trailing edge of the multiple CAER01 entries. The output is in the aerodynamic panel coordinate system so that the sign of the forces and moments are a function of the numbering of the corners of the panel. The results are given for the aeroelastic trim state.

Special Considerations for the MONPNT3

In a typical scenario, the MONPNT3 process identifies the elements that participate in the calculation of the monitor point result and then does a mini EMA (element matrix assembly) to form a stiffness matrix that just includes those elements. Multiplying this matrix by an integration matrix that transfers forces to the monitor point results in a matrix S that can be multiplied by the set of solution vectors U to provide the monitor point results:

$$MP3 = S^T U \tag{3-3}$$

The S matrix (denoted MP3INT in the dmap sequences) is computed as a preprocessing operation. The monitor point results are then calculated using Equation (3-3) once the displacements have been computed.

The exclusion flag (XFLAG) has special significance in this process. This flag can be used to exclude specified force types from the calculation. If the XFLAG field is set by the user to exclude all of the candidate force types (i.e., XFLAG=SMAD), then the enhanced algorithm can be employed and a filtering process is applied to see which set of the elements and grids listed in the GRIDSET and ELEMSET will result in a non-zero resultant force. I.e., if all the elements attached to a particular grid are included in the ELEMSET, the grid can be filtered out and if all the grids a particular element attaches to are included in the GRIDSET, then the element can be filtered out. The remaining grids and elements are then included in the mini-EMA step.

If the XFLAG is blank, then a complementary filtering process occurs. Excluding of grids and elements occurs as above but now the remaining set of elements is discarded and the mini-EMA includes those elements that are attached to the retained grids that are NOT included in the ELEMSET.

If some, but not all, of the candidate force type are excluded (e.g., XFLAG=A), then Equation (3-3) cannot be applied and the MONPNT3 processing reverts to a computationally more intensive grid point force methodology.

Use of External Superelements in Aerodynamic Analysis

An external superelement is a model of a component or collection of components which are reduced to a set of boundary points on a **generation** run and stored on a permanent file. The external superelement itself may have superelements included in it, or it may have only a residual structure. The a-set points of its residual structure become the boundary points of the external superelement. The boundary points are attached to another model on a subsequent **assembly** run, and the total assembled model is solved.

Typically, large, detailed models of engines are provided by engine manufacturer to aircraft developers. The aircraft developer attaches this engine model at several places in one aircraft model and plans to attach it to many other aircraft models over time. The aircraft modeler does not want to modify the engine model, even inadvertently. He also wants the IDs of the grid points and elements of the aircraft to be independent of the IDs used in the engine model. The latter requirement is met by making the engine model a part superelement. The former requirement is met by analysing the engine model once in a stand-alone generation run, then attaching the boundary matrices which result from this run to many other models. The cost of reducing the engine model is paid only once, and the engine model cannot be changed inadvertently on subsequent runs.

Generation Run

The engine modeler wants to make sure that his model is thoroughly validated before it is turned over to the aircraft developer. The engine modeler also knows which structural points are capable of taking loads imposed by aerodynamic forces. The engine modeler therefore also prepares the CAERO-type and splining data for his component. He can use this data to check the aeroelastic behaviour of his model by grounding the engine attach points in a checkout run which simulates a wind tunnel experiment. After the model has passed all the checkout and validation runs, he removes the ties to ground which simulate the wind tunnel condition and passes the input file for the engine model to the aircraft developer.

The engine model is analysed and reduced to its boundary matrices in the generation run. This run places the boundary matrices in an engine model database. This database and bulk data entries which define the geometry and connectivity of the interface points are added to a model where the total aircraft is analysed.

All CAERO-type data, that is, the CAEROi entries and other entries referenced on a CAEROi entry, and the spline data, is placed in the main Bulk Data Section because these are grid list superelements. In the superelement spline method for internal superelements (that is, list and part superelements in the same input file) it is necessary to place all CAEROi entries for the entire engine model in the main Bulk Data Section. This allows the columns of the spline matrices to be properly aligned. This requirement is relaxed for external superelements. The engine modeler inputs CAERO-type entries only for the components in his model. A device is added to the total aircraft model, described later, which performs this alignment function.

Assembly Run

The assembled aircraft model should contain an FMS section with ASSIGN statements for the databases created in the previous generation run. The same database (and its associated matrices) can be used to model multiple engines in this assembly run and needs to be associated with a separate external superelement ID for each engine.

The external superelement geometry is described in part superelement files starting with the delimiter BEGIN SUPER=[SEID]. A “PARAM, FIRSTKI, I” statement lists the location of the first k-set point corresponding to the first CAEROi point in the external superelement. The internal sequence of the k-set DOFs is a closed set starting with a value of 1. The lowest-numbered CAEROi entry uses the first internal number, followed by a set of numbers in the range NSPAN*NCHORD-1 for the remaining points defined on that CAEROi entry. The next lowest-numbered CAEROi entry starts with the next available internal number. To get the corresponding FRISTKI for each CAEROi entry, “PARAM, USETPRT, 0” is added the first time an assembly model is run to print the correlation of external sequence numbers of aero points with their internal sequence number. The location of the first related k-set point is then obtained from the “K DISPLACEMENT SET” written out.

It is essential that the FIRSTKI values be input correctly as they are used to make a partitioning vector that inserts the spline matrices for the corresponding superelements in the proper columns. Some checks for necessary but not sufficient attributes are made to determine that the columns have been inserted properly. One such check is for the presence of null columns in the total assembled spline matrix. All null columns are identified in terms of their k-set index. While null columns may be permissible in some circumstances, they are usually an indication of a modelling error, and should be checked out. A corollary of this discussion is that if the external superelement has more than one CAEROi entry their Ids must be numbered such that they are adjacent to each other in the sorted sequence of the assembly input file. Also note that all CAEROi entries are placed in the same interference group to couple their aerodynamic effects.

The above points and other related connectors between the generation run and the assembly run are better explained in the examples HA145SS7 and HA145SS8 in Chapter 8: Flutter Analysis Problems.

4 Input Files for Aeroelastic Problems

Overview

Before an aeroelastic analysis can be performed, it is necessary to have an input file for the finite element structural model that satisfies the descriptions in the *MSC Nastran Quick Reference Guide* regarding the Executive Control statements (Section 3), the Case Control commands (Section 4), and the Bulk Data entries (Section 5). The descriptions of the input files in this chapter contains only the information related to the features that must be included in the input file to obtain a static aeroelastic, flutter, or dynamic aeroelastic response analysis, or aeroelastic design sensitivity and optimization.

Executive Control Section

A user typically runs MSC Nastran by invoking one of the standard solution sequences. These sequences are a collection of DMAP statements that drive the analysis and the aeroelastic sequences are described in Aeroelastic Solution Sequences. The aeroelastic analysis and design solution sequences are:

SOL 144	STATIC AEROELASTIC RESPONSE
SOL 145	AERODYNAMIC FLUTTER
SOL 146	DYNAMIC AEROELASTIC RESPONSE
SOL 200	SENSITIVITY AND OPTIMIZATION

Solution 200, in addition to performing sensitivity and optimization, is also a multidisciplinary analysis procedure. This solution sequence contains the analysis capabilities of SOLs 101 (Statics), 103 (Normal Modes), 105 (Buckling), 107 (Direct Complex Eigenanalyis), 108 (Direct Frequency Response), 110 (Modal Complex Eigenanalysis), 111 (Modal Frequency Response), 112 (Modal Transient Response), 144 (Static Aeroelasticity), and 145 (Aerodynamic Flutter). This makes it possible to perform static aeroelastic and flutter analyses in a single run.

Case Control Section

Case Control data selection commands available for aeroelastic solutions are listed here. The *MSC Nastran Quick Reference Guide* should be consulted for the most up-to-date description of these entries. This section provides a brief description of each of the commands.

Configuration Selection

AECONFIG	Assigns aerodynamic configuration
AERCONFIG	Assigns rigid aerodynamic configuration
AESYMXY	Specifies aerodynamic symmetry about the xy plane (ground effect)
AESYMXZ	Specifies aerodynamic symmetry about the xz plane

Static Aeroelastic Trim Variable Selection

TRIM	Selects a TRIM Bulk Data entry in static aeroelastic response.
CSSCHD	Selects control system schedule information.
AEUXREF	Selects reference UXVEX about which point the stability derivatives are calculated.

Divergence Solution Selection

DIVERG	Selects the number of eigenvalues and Mach numbers for the aeroelastic divergence analysis.

Structural Damping and Transfer Function Selection

SDAMPING	Selects a table that defines damping as a function of frequency.
TFL	Selects the transfer function set that represents a servomechanism.

Aeroelastic Flutter Solution Selection

FMETHOD	Selects the method to be used in aerodynamic flutter analysis.
CMETHOD	Selects a complex eigenvalue method for flutter analysis.
METHOD	Selects a real eigenvalue method for vibration analysis.

Dynamic Aeroelastic Load Selection

DLOAD	Selects the dynamic load to be applied in a transient or frequency response problem.
FREQUENCY	Selects the set of frequencies to be solved in frequency response problems.
GUST	Selects the gust load in aeroelastic response analysis.
RANDOM	Selects the RANDPS and RANDTi entries to be used in random analysis.
TSTEP	Selects integration and output time steps for transient problems.

Output Control

AEROF	Requests the aerodynamic loads on the aerodynamic control points.
AEUXREF	Defines the reference aerodynamic extra point (controller) vector
APRESSURE	Requests the aerodynamic pressures in static aeroelastic response.
TRIMF	Specifies options for the output of trim loads from a static aeroelastic analysis.

Bulk Data Section

The Bulk Data entries required in the analysis of finite element models are described in the Bulk Data Entries in the *MSC Nastran Quick Reference Guide*. This section provides a brief comment on those entries that are unique to MSC Nastran's aeroelastic capability. Table 4-1 presents a list of these entries and indicates which ones are required (R) and available (A) in each of the solution sequences. SOL 146 typically requires significant dynamic analysis input [see the *MSC Nastran Dynamic Analysis User's Guide*] and SOL 200 typically contains significant design model input [see the *MSC Nastran Design Sensitivity and Optimization User's Guide*] that is not included here.

Table 4-1 Bulk Data Entries for Aeroelasticity

Bulk Data Entry	Solution			
	144	145	146	200
AECOMP	A		A	A
AECOMPL	A		A	A
AEDW	A			A
AEFACT	A	A	A	A
AEFORCE	A			A
AEGRID	A			A
AELINK	A			A
AELIST	A	A	A	A
AELISTC	A			A
AEPARM	A			A
AEPRESS	A			A
AEQUAD4	A			A
AESCALE	A			A
AESURFS	A			A
AETRIA3	A			A
AERO		R	R	A
AEROS	R			A
AESTAT	A			A
AESURF	A			A
CAERO1	A	A	A	A
CAERO2	A(1)*	A	A	A
CAERO3	A(2)	A	A(3)	A
CAERO4	A(2)	A	A(3)	A

Table 4-1 Bulk Data Entries for Aeroelasticity (Continued)

Bulk Data Entry	Solution			
	144	145	146	200
CAERO5	A(2)	A	A(3)	A
CSSCHD	A			A
DIVERG	A			A
DMIJ	A			A
DMIJI	A			A
DMIK	A			A
FLFACT		R		A
FLUTTER		R		A
GUST			A	A
MKAERO1		R(4)	R(4)	A
MKAERO2		R(4)	R(4)	A
MONCNCM	A			A
MONDSP1	A		A	A
MONGRP	A		A	A
MONPNT1	A		A	A
MONPNT2	A		A	A
MONPNT3	A		A	A
MONSUM	A		A	A
MONSUM1	A		A	A
MONSUMT	A		A	A
PAERO1	A	A	A	A
* Parenthetical numbers refer to the notes at the end of the table.				

Table 4-1 Bulk Data Entries for Aeroelasticity (Continued)

Bulk Data Entry	Solution			
	144	145	146	200
PAERO2	A(1)	A	A	A
PAERO3	A(2)	A	A(3)	A
PAERO4	A(2)	A	A(3)	A
PAERO5	A(2)	A	A(3)	A
PARAM	A	A	R(5)	A
SET1	A	A	A	A
SET2	A	A	A	A
SPBLND1	A	A	A	A
SPBLND2	A	A	A	A
SPLINE1	A	A	A	A
SPLINE2	A	A	A	A
SPLINE3	A	A	A	A
SPLINE4	A	A	A	A
SPLINE5	A	A	A	A
SPLINE6	A	A	A	A
SPLINE7	A	A	A	A
SPLINEX	A	A	A	A
SPLNRB	A	A	A	A
SPRELAX	A	A	A	A
TABRNDG			A	
TRIM	A			A
UXVEC	A			A

Note:	
	■ CAERO2 and PAERO2 entries provides slender body aerodynamics and are only available for subsonic analyses. ■ In SOL 144, CAEROi and PAEROi for i = 3, 4, or 5 are not available for TRIM analysis; they can be used for DIVERGENCE analysis. ■ In SOL 146, CAEROi and PAEROi for i = 3, 4, or 5 are not available for GUST analysis but can be used for dynamic aeroelastic analysis with nonaerodynamic loading (for example, store ejection or landing loads). ■ At least one MKAERO1 or MKAERO2 entry must be present for flutter and dynamic aeroelastic analyses. ■ For dynamic aeroelastic analysis, the Q parameter is required.

The descriptions of the Bulk Data entries found in Bulk Data Entries in the *MSC Nastran Quick Reference Guide* are intended to be comprehensive so that extended descriptions are not presented here. Instead, brief comments are given which highlight features of the entry, particularly those that have been troublesome to users

AECOMP	Components invoked on the MONDSP1, MONPNT1 or SPLINEX entry. The components can be structural or aerodynamic.
AECOMPL	A list of components. Structural and aerodynamic components must be kept separate.
AEDW	Definition of a downwash vector that is used in nonlinear aeroelastic trim analysis. For internal aerodynamics (e.g., doublet lattice), this is an alternative to the W2GJ DMI entry.
AEFACT	Specifies lists of real numbers for the aerodynamic model required by the CAEROi and PAEROi entries. When the data refer to spanwise, chordwise, or bodywise division cuts, the data are in fractions of the span, chord, and body length, respectively.
AEFORCE	Definition of an aerodynamic force vector that is used in a nonlinear aeroelastic analysis.
AEGRID	Defines the location of an aerodynamic grid point. The AEGRID, AEQUAD4, AETRIA3 and AESCALE entries can be used to define an aerodynamic surface that DOES NOT internally produce aerodynamics. Instead the user must provide the associated aerodynamics externally.
AELINK	Links aerodynamic extra points.
AELIST	Defines aerodynamic elements associated with a control surface in static aeroelasticity.
AELISTC	List of character names used only by the SPLINEX entry.
AEPARM	A general aerodynamic trim variable that augments those specified on AESTAT or AESURF entries. These controllers can represent gimbal angles, thrust levels, or any other force variation on the vehicle. The force vectors associated with these variables are input by the user via; e.g., AEFORCE entries.

AEPRESS	Defines a loading vector as a pressure field over the aerodynamic mesh. For internal aerodynamics (e.g., doublet lattice) this is an alternative to the FA2J DMI entry.
AEQUAD4	Connectivity of a quadrilateral aerodynamic mesh element. See AEGRID.
AESCALE	Defines reference lengths to scale aerodynamic grid points. If no scaling is required, this entry can be omitted. See AEGRID
AERO	Aerodynamic parameter for unsteady aerodynamics. Note that aerodynamic densities must be in consistent units; that is, PARAM WTMASS does not apply to RHOREF.
AEROS	Aerodynamic parameters for steady aerodynamics. The reference area (REFS) is input for half the vehicle when a half-span model is used. The reference span (REFB) is always the full vehicle span.
AESTAT	Rigid body aerodynamic extra points. A number of prespecified labels are provided to invoke standard rigid body motions such as angle of attack or roll. If other labels are used, the burden is on the user to provide the corresponding forces.
AESURF	Aerodynamic control surface extra points.
AESURFS	Optional specification of the structural nodes associated with an aerodynamic control surface. The mass associated with these grids provide the control surface moments of inertia about the hinge line.
AETRIA3	Connectivity of a triangular aerodynamic mesh element. See AEGRID.
CAERO1	Defines a wing panel for Doublet-Lattice and/or ZONA51. The leading edge locations are input in the CP coordinate system of the entry while the edge chords are in the aerodynamic coordinate system specified by the AERO or AEROS entry. This convention also applies to the other CAEROi entries.
CAERO2	Body data for Doublet-Lattice aerodynamics.
CAERO3	Panel data for Mach Box aerodynamics.
CAERO4	Panel data for Strip Theory aerodynamics.
CAERO5	Panel data for Piston Theory aerodynamics. Sweep corrections (NTHRY = 2) cannot be used when the leading edge is subsonic $sec\Lambda \geq M$
CSSCHD	Defines a scheduled control surface deflection as a function of Mach number and angle of attack.
DIVERG	Specifies static aeroelastic divergence analysis.
DMIJ	Direct matrix input of aerodynamic terms (e.g., pressure or downwash) at aerodynamic collocation points. This can be used for any of the aerodynamic panel methods for internal aero and for external aerodynamics and for slender body elements and for AEPRESS and AEDW data for external aerodynamics.
DMIJI	Direct matrix input of aerodynamic terms (e.g., pressure or downwash) at slender body collocation points. This is used for interference bodies with slender body theory.
DMIK	Direct input of aerodynamic forces at ks degrees of freedom. This can be used to input correction factor matrices (WKK or WTFACT) or external aerodynamic forces.

FLFACT	Specification of real number required in a flutter analysis or a flutter sensitivity analysis. The alternate form is useful for obtaining a good distribution of k-values for V-G flutter plots when using the KE-flutter method.
FLUTTER	Specifies flutter analysis. IMETH = S permits interpolation of the computed aerodynamic data on both Mach number and reduced frequency when employing the K- or KE-methods of flutter analysis.
GUST	Specification of vertical gust parameters. The value of V on this entry must be identical with the VELOCITY input on the AERO entry.
MKAERO1	Specification of Mach number and reduced frequencies for aerodynamic matrix calculations.
MKAERO2	Alternate specifications of Mach numbers and reduced frequencies for aerodynamic matrix calculations.

NOTE: The MONxxxx entries deal with monitor points. These are powerful tools for extracting loads, element and displacement results from an analysis. Monitor points were initially implemented in MSC Nastran as part of the static aeroelastic analysis, but they are now used in many other linear solution sequences (101,103,108,109,111,112,144,146 and 200). A brief description of monitor points with simple examples is provided in the section on Monitor Points in the *MSC Nastran Linear Static Analysis User's Guide*.

MONCNCM	This entry provides nondimensional force and moment on aerodynamic strips from a model generated using CAERO 1 data for static aeroelasticity (SOLs 144 and 200)
MONDSP1	Defines a virtual point displacement response at a user-defined reference location
MONGRP	Defines a collection of monitor points into a group available for postprocessing.
MONPNT1	Defines an integrated load monitor point at a point (x.y.z) in a user defined coordinate system. Unavailable in SOL 103.
MONPNT2	Element monitor point.
MONPNT3	Sums select Grid Point Forces to a user chosen monitor point.
MONSUM	Sums existing monitor points to create a new monitor point with no reference to location or coordinate system.
MONSUMI	Sums existing monitor points to create a new monitor point at a user specified location and coordinate system.
MONSUMT	Sums existing monitor points to create a new monitor point at a user specified location and coordinate system while taking moment transfer into account.
PAERO1	Defines bodies associated with CAERO1 entries. A PAERO1 entry is required even when there are no bodies. Note that panels and bodies can be in the same interference group (IGID on the CAERO1 and CAERO2 entries) but not be associated. Associated bodies must be in the same interference group as the referencing panel.

PAERO2	Defines body properties. See Slender and Interference Bodies for an extensive discussion of this entry.
PAERO3	Additional specifications for Mach Box aerodynamics.
PAERO4	Additional specification for Strip Theory aerodynamics.
PARAM	This entry, which may also appear in the Case Control Section, is used to provide scalar values used in performing solutions. Parameters in the *MSC Nastran Quick Reference Guide* has a comprehensive discussion of all the MSC Nastran PARAMs. Parameters for Aeroelastic Analysis and Design of this guide contains the subset of parameters that are unique to the aeroelastic solutions.
SET1	Selects grids to be used in the splining of aerodynamics. This entry is also used to select flutter modes to be used in flutter sensitivity and optimization.
SET2	An alternative specification of the grids to be used in the splining of aerodynamics.
SPBLND1	Blends two splines based on the distance from a specified grid.
SPBLND2	Blends two splines based on the distance from a specified curve.
SPLINE1	Specification of the two-dimensional spline.
SPLINE2	Specification of the one-dimensional spline.
SPLINE3	Alternative specification of the splining between structural and aerodynamic grids. Although this is provided primarily for control surfaces, it has general applicability.
SPLINE4	Curved surface spline.
SPLINES	General 1D spline.
SPLINE6	Three degree of freedom (3DOF) or 6DOF surface spline used for general aerodynamic meshes.
SPLINE7	6DOF beam spline for general aerodynamic meshes.
SPLNRB	Rigid body spline
SPRELAX	Provides for relaxation of a spline based on an adjacent spline.
TABRNDG	Provides the simplified specification of atmospheric gust power spectral densities. The TABRND1 entry is available for the specification of spectra not supported by this entry.
TRIM	Specifies a trim flight condition.
UXVEC	Specification of a vector of aerodynamic control point (extra point) values. These data define the control positions corresponding to user defined nonlinear control forces that have been defined by AEDW,AEPRESS and AEFORCE entries.

Parameters

FIRSTKI	This lists the location of the first k-set point of the first CAEROi point related to each superelement, SEID.

PARAM Bulk Data entries are used in the DMAP sequences for input of miscellaneous data and to request special features. The most important parameters used in aeroelastic analysis and design are described in alphabetical order. The complete description of all parameters is contained in Parameters in the *MSC Nastran Quick Reference Guide*, and the user should refer to that section for current features. Additionally, miscellaneous parameters are specified using the MDLPRM bulk data entry. Aeroelastic related parameters are listed at the end of this section.

G	Default = 0.0 G specifies the uniform structural damping coefficient in the formulation of dynamics problems. To obtain the value for the parameter G, multiply the critical damping ratio, C/C_o, by 2.0.
GUSTAERO	Default = 1 If gust loads are to be computed, for example on restart, set `GUSTAERO` to -1. The default is recommended if no gust loads are to be computed after the flutter analysis.
HFREQ	Default = 1.+30 The parameters `LFREQ` (lower limit) and `HFREQ` (upper limit) specify the frequency range in cycles per unit time of the modes to be used in the modal formulations. The default for `HFREQ` will usually include all vectors computed. A related parameter is `LMODES`.
KDAMP	Default = 1 If `KDAMP` is set to -1, viscous modal damping is entered into the complex stiffness matrix as structural damping. See Section 9.4.10 of the *MSC Nastran Reference Guide*.
LFREQ	Default = 0.0 Se `HFREQ`.
LMODES	Default = 0 `LMODES` is the number of lowest modes to use in a modal formulation. If `LMODES` = 0, the retained modes are determined by the parameters `LFREQ` and `HFREQ`. In coupled fluid-structure analysis, `LMODES` is applied only to the structural portion of the model.
MACH	Default = 0.0 Mach number. If more than one Mach number was used to compute aerodynamic matrices, the one closest to `MACH` will be used in dynamic aeroelastic response analysis. As a default, the matrices computed at the lowest `MACH` number is used.

OPGEOM	Default = -1 `OPGEOM > -1` prints the aerodynamic sets definitions for the aerodynamic mesh with the following options: (see table below) The USETPRT parameter description in Quick Reference Guide provides further information of structured sets that is applicable to the aerodynamic sets.
OPGTKG	Default = -1 `OPGTKG > -1` prints the matrix for the interpolation between the structural and aerodynamic degrees of freedom.
OPPHIPA	Default = -1 This parameter is valid in the flutter (SOLs 145) and aeroelastic (SOLs 146) solution sequences. `OPPHIPA > -1` and a `DISPLACEMENT` command in the Case Control Section will output the real vibration modes at all degrees of freedom, including the aerodynamic degrees of freedom.

Sequence	Print	USETPRT
None	None (Default)	-1
	Row sort only	0
Internal	Column sort only	1
	Row and Column sort	2
	Row sort only	10
External	Column sort only	11
	Row and Column sort	12

PRINT	Default = YES `PARAM,PRINT,NO` suppresses the automatic printing of the flutter summary in flutter analysis.
Q	Default = 0.0 Q specifies the dynamic pressure. Q must be specified in aeroelastic response analysis (SOLutions 76 and 146) and the default value will cause a User Fatal Message.
SKPAMP	Default = 0 For Solutions 145, 146, and 200, `SKPAMP` = -1 suppresses all unsteady aerodynamic calculations. The automatic restart of structural solution sequences performs a similar function without this parameter. Specifying it ensures the suppression of the calculations, regardless of the determination of the automatic restart.

VREF	Default = 1.0 In modal flutter analysis, the velocities are divided by `VREF` to convert units or to compute flutter indices.
Aeroeslatic related parameters entered using the MDLPRM bulk data entry.	
MLTSPLIN	Specifies whether an aerodynamic grid can be referenced by more than one spline
SPBLNDX	Factor to be applied to Dl and D2 spline depths on the SPBLND1 and SPBLND2 bulk data entries for determining the structural grids on the blended region

Restarts

A powerful feature of MSC Nastran is its ability to use previously computed results in a subsequent analysis. The “restart” capability is briefly described in Restart Procedures in the *MSC Nastran Reference Guide*. This subsection first lists common scenarios in an aeroelastic analysis that would benefit from the restart capability and then provides input data, with examples, required to perform the restart.

When to Use Restarts

Restarts are of prime benefit when a given analysis requires significant resources in terms of CPU time, turnaround time, or computer disk space, and where the user expects to make a number of changes to the original analysis. In these situations it is desirable to make a primary run in a “cold” start and save the database for access in subsequent runs. In aeroelastic analyses, a significant portion of the resources are consumed in generating the aerodynamic matrices for the aerodynamic model. For this reason, restarts are recommended for the following aeroelastic operations:

1. Investigate changes in the aerodynamics model while leaving the structural model unchanged.
2. Investigate changes in the structural model while leaving the aerodynamic model unchanged.
3. Perform additional analyses using the same aerodynamic and structural models, such as:

   Change the velocities at which a PK-flutter analysis is performed.

   Change the dynamic pressure in an aeroelastic gust analysis.

   Perform a trim analysis at a new flight condition.
4. Add an m,k pair to refine the aerodynamic interpolation.
5. Continue a run after it has exceeded its time limit in the cold start.
6. Feed information from another solution sequence, such as Nonlinear Heat Transfer (SOL 106) into an aeroelastic solution.

When Not to Use Restarts

With the performance available in present-day computers, resource limits are much less significant than they were in the past. For this reason, even the minor inconveniences caused by working with a database are often not justified, and the use of restarts is restricted to large analysis models acting in a “production” environment.

Also, in the early stages of model development, it is likely that numerous changes will be made that will make restarting of minimal benefit.

Examples

In order to perform a restart run, the cold start run has to have been performed and the database saved. This is done by submitting the cold start using the SCR = NO qualifier; for example,

```
nastran ha44a scr=no
```

The examples presented below assume this cold start has been made. For the restart run, the database has to be invoked with a command of the form:

```
nastran ha144a_rst scr=no dbs=ha144a
```

Modifying the Aerodynamic Model

Suppose it is desired to determine the effect of increasing the aspect ratio of the HA144A wing (see FSW Airplane in Level Flight from 4 to 5. Furthermore, suppose that there is no interest in the low dynamic pressure trim results or the supersonic analysis (subcases 1 and 3) described in Example HA144A. This requires changes in the AEROS entry and the CAERO1 entry that models the wing, with the remaining Bulk Data entries unchanged. The input data file for the restart is shown in Listing 4-1. The restart simply entails the addition of a RESTART request in the File Management Section, the removal of the first subcase, and the replacement of the changed Bulk Data entries. The / entry removes entries on restart based on the sorted Bulk Data echo of the cold start.

Note that for restart purposes the aerodynamic model is considered modified if any CAEROi, PAEROi, AEFACT, AERO, or AEROS Bulk Data entry is changed. If coordinate systems called out by these entries change, the modification is not detected, and a restart should not be used.

Listing 4-1 Restart Input File for Modifying the Aerodynamic Model of Example HA144A

```
RESTART, VERSION=1, KEEP
SOL 144 $ STATIC AERO
CEND
TITLE = EXAMPLE HA144A: 30 DEG FWD SWEPT WING WITH CANARD HA14 HA144A
SUBTI = SYMMETRIC FLIGHT CONDITIONS, DOUBLET-LATTICE AERO
LABEL = HALF-SPAN MODEL, STATIC SYMMETRIC LOADING
  ECHO    = BOTH
  SPC     = 1   $ SYMMETRIC CONSTRAINTS
  DISP    = ALL $ PRINT ALL DISPLACEMENTS
  STRESS  = ALL $ PRINT ALL STRESSES
  FORCE   = ALL $ PRINT ALL FORCES
  AEROF   = ALL $ PRINT ALL AERODYNAMIC FORCES
  APRES   = ALL $ PRINT ALL AERODYNAMIC PRESSURES
SUBCASE 2
  TRIM = 2      $ 1 G LEVEL FLIGHT (HIGH SUBSONIC SPEED)
BEGIN BULK
/delete aeros,caero1
AEROS   1        100    10.0    50.0    250.0   1
CAERO1  1100    1000            8       4                       1
        25.     0.      0.      10.     10.56624 25.    0.      10.
CAERO1  1000    1000            2       4                       1
        10.     0.      0.      10.     10.     5.      0.      10.
ENDDATA
```

Modifying the Structural Model

Suppose that in the sweptback wing the flutter analysis of Subsonic Flutter Analysis of the 15-Degree Sweptback Wing by the KE-Method (Example HA145E) the effects of increasing the thickness of the plate from 0.041 to 0.05 were to be investigated. This thickness value is input on the PSHELL entry as well as the leading and trailing edge CQUAD4 entries. Furthermore, no V-G plots are required in this reanalysis. Listing 4-2 shows the restart input data file.

Listing 4-2 Restart Input File for Modifying the Structured Model of HA146E

```
RESTART VERSION=1, KEEP
ID MSC, HA145E-rst $
SOL 145  $ FLUTTER ANALYSIS
CEND
TITLE = EXAMPLE HA145E: HALF SPAN 15-DEG SWEPT UNTAPERED WING  HA145E
SUBT  = KE-METHOD FLUTTER ANALYSIS, DOUBLET-LATTICE AERO
LABEL = 0.041 IN AL PLATE W/BEVELLED LEADING AND TRAILING EDGES
  ECHO    = BOTH
  SPC     = 1   $ WING ROOT DEFLECTIONS AND PLATE IN-PLANE ROTATIONS FIXED
  SDAMP   = 2000
  METHOD  = 10  $ MODIFIED GIVENS METHOD OF REAL EIGENVALUE EXTRACTION
  FMETHOD = 30  $ KE-FLUTTER METHOD SVEC    = ALL $ PRINT VIBRATION MODES BEGIN BULK
begin bulk
/delete pshell,cquad4
PSHELL  1       1       .050    1               1
CQUAD4  1       1       1       2       10      9
                         0.0     0.0     .050    .050
CQUAD4  2       1       2       3       11      10
                         0.0     0.0     .050    .050
CQUAD4  3       1       3       4       12      11
                         0.0     0.0     .050    .050
CQUAD4  4       1       4       5       13      12
                         0.0     0.0     .050    .050
CQUAD4  5       1       5       6       14      13
                         0.0     0.0     .050    .050
CQUAD4  6       1       6       7       15      14
                         0.0     0.0     .050    .050
CQUAD4  7       1       7       8       16      15
                         0.0     0.0     .050    .050
CQUAD4  8       1       9       10      18      17
CQUAD4  9       1       10      11      19      18
CQUAD4  10      1       11      12      20      19
CQUAD4  11      1       12      13      21      20
CQUAD4  12      1       13      14      22      21
CQUAD4  13      1       14      15      23      22
CQUAD4  14      1       15      16      24      23
CQUAD4  15      1       17      18      26      25
CQUAD4  16      1       18      19      27      26
CQUAD4  17      1       19      20      28      27
CQUAD4  18      1       20      21      29      28
CQUAD4  19      1       21      22      30      29
CQUAD4  20      1       22      23      31      30
CQUAD4  21      1       23      24      32      31
CQUAD4  22      1       25      26      34      33
                         .050    .050    0.0     0.0
CQUAD4  23      1       26      27      35      34
                         .050    .050    0.0     0.0
CQUAD4  24      1       27      28      36      35
                         .050    .050    0.0     0.0
CQUAD4  25      1       28      29      37      36
                         .050    .050    0.0     0.0
CQUAD4  26      1       29      30      38      37
                         .050    .050    0.0     0.0
CQUAD4  27      1       30      31      39      38
                         .050    .050    0.0     0.0
CQUAD4  28      1       31      32      40      39
                         .050    .050    0.0     0.0
ENDDATA
```

Postprocessing of Model Data

If it is desired to change some aspect of an original analysis other than the structural model or the aerodynamic model, the restart can be thought of as a postprocessing operation. The MSC Nastran restart capability is particularly powerful in this scenario since the CPU-intensive tasks are only performed in the cold start.

As an example, the previous example with the increased plate thickness demonstrates a flutter speed in the 620-640 ft/sec range. Suppose it is desired to study this range more intensively for all the modes using a PK-flutter analysis. Relative to the run of the previous example, this requires changing the FLUTTER Bulk Data entry and the `FLFACT` entry that previously specified reduced frequencies and now must specify velocities. Listing 4-3 shows the restart input data file for this case. Note that the analysis velocities have been input using physically consistent units of in/sec. Furthermore, note that VERSION = 3 is specified on the `RESTART` command. This is the version that contains results from the successful restart run of the previous example. If there is doubt as to the correct version, the `F04` file of the successful run identifies the version that contains the desired information.

Listing 4-3 Restart Input File for Modifying the Flutter Method from the Input File Shown in Listing 4-2

```
RESTART VERSION=1, KEEP
ID MSC, HA145E-ref $
SOL 145  $ FLUTTER ANALYSIS
CEND
TITLE = EXAMPLE HA145E: HALF SPAN 15-DEG SWEPT UNTAPERED WING  HA145E
SUBT  = KE-METHOD FLUTTER ANALYSIS, DOUBLET-LATTICE AERO
LABEL = 0.041 IN AL PLATE W/BEVELLED LEADING AND TRAILING EDGES
  ECHO    = BOTH
  SPC     = 1   $ WING ROOT DEFLECTIONS AND PLATE IN-PLANE ROTATIONS FIXED
  SDAMP   = 2000
  METHOD  = 10  $ MODIFIED GIVENS METHOD OF REAL EIGENVALUE EXTRACTION
  FMETHOD = 30  $ KE-FLUTTER METHOD SVEC    = ALL $ PRINT VIBRATION MODES BEGIN BULK
begin bulk
/ delete flutter, flfact
FLUTTER 30      PK      1       2       3
FLFACT  1       0.967                                                   DENSITY
FLFACT  2       .45                                                     MACH NO
FLFACT  3       7440.7500.7560.7620.7680.
ENDDATA
```

Addition of m,k Pairs

Modification of the MKAEROi entries represents a special case in that neither the aerodynamic or structural models have changed, but additional aerodynamic analyses are required. Before these calculations are made, a check is done to see if the aerodynamic matrices exist for a particular m and k. If they do, the calculation is skipped. Listing 4-4 shows the input data file required for a restart of Examples HA146D and Frequency Response of BAH Wing to Oscillating Aileron (Examples HA146D and HA146DR) with an additional m,k pair of m = 0.0 and k = 0.2.

Listing 4-4 Input Data File for Adding a Mach Number and Reduced Frequency Pair to Example HA146D

```
RESTART VERSION=1, KEEP
SOL 146                     $ AEROELASTIC RESPONSE
CEND
TITLE = BAH WING DYNAMIC FREQUENCY RESPONSE HA146D            HA146D
SUBTI = ANTISYMMETRIC RESPONSE, DOUBLET LATTICE AERO
LABEL = UNIT HARMONIC AILERON ROTATION
ECHO = BOTH
  SPC = 13                 $ BOUNDARY CONDITIONS (ANTISYMMETRIC)
  MPC = 1                  $ CONTROL SURFACE RELATIVE MOTION
  METHOD = 10              $ MODIFIED-GIVENS EIGENVALUE METHOD
  K2PP = ENFORCE           $ EPOINT ADDED VIA DMIG
  SDAMP = 2000             $ STRUCTURAL DAMPING (3 PERCENT)
  DLOAD = 1000             $ FREQUENCY DEPENDENT LOAD
  FREQ = 40                $ FREQUENCY LIST
  SET 1 = 11
  SPCF(PHASE,sort2) = 1          $ SINGLE POINT CONSTRAINT FORCES
BEGIN BULK
MKAERO10.0
0.20
ENDDATA
```

5 Output Features and Interpretation

Overview

Aeroelastic analysis and design involves four solution sequences (SOLs 144, 145, 146, and 200). Each solution has its own standard output format and each can be supplemented with additional output obtained by appropriate Case Control commands and the use of parameters (PARAMs) in the Bulk Data or Case Control files. The examples of Chapter 7: Static Aeroelastic Analysis Problems through Chapter 9: Dynamic Aeroelastic Response Analysis provide a comprehensive description of the aeroelastic output so that this chapter is limited to a short description of the output and an indication of where it is described and depicted in the examples.

Static Aeroelasticity

Stability Derivatives

Nondimensional stability derivatives are printed for any static aeroelastic analysis that includes SUPORT degrees of freedom and for as many degrees of freedom as are SUPORTed. FSW Airplane in Level Flight provides a description of this output while Listing 7-3, Listing 7-9, et al., provide examples.

HP0 and HP Matrices

The HPO and HP matrices are used to determine mean axis rotation angle derivatives that can be used, for example, in time simulation studies that use restrained aeroelastic coefficients in the equations of motion. The number of rows in these matrices correspond to the number of SUPORTed degrees of freedom. The HP0 matrix is for the intercept input (for example, user input pressures and downwash angles) while the HP matrix contains data for each of the AESTAT and AESURF entries in the same order as they appear in the stability derivative print. FSW Airplane in Level Flight provides a description of how to interpret these data for a longitudinal analysis while FSW Airplane in Antisymmetric Maneuvers contains a lateral example.

Trim Variables

The results of the trim analysis for all the aerodynamic extra points are always printed for each subcase. The values are in the units inferred on the AESTAT Bulk Data entry or specified on the AEPARM bulk data entry or in radians for AESURF derived extra points. Each of the output listings in Static Aeroelastic Analysis Problems contains at least one example of this output.

Hinge Moment and Total Vehicle Coefficients

Hinge moment output is provided for each AESURF entry and indicates the moment induced by each of the aerodynamic extra points at the control surface hinge line.

Coefficients in wind and body axes based on structural and aerodynamic monitor points provide guidance as to the source of the loads.

The values are shown as the "RIGID AIR" (actually parametric loads including structural parametric loads from AEFORCE) and the restrained increment. Then the inertial loads (if structural monitor points—

aerodynamic monitor points cannot compute inertial loads, so they are marked "N/A"). Next there are two columns for the rigid structural applied load (not a parametric load) and its inertial increment. Finally the summation or "BALANCE" load coefficient is printed. Notice that the addition or subtraction to achieve the balance load is shown on the title line.

For the aerodynamic monitor points, the balance load will not typically be zero, since the aerodynamic loads are balancing inertial loads which cannot be measured on the aerodynamic mesh. Consequently, the imbalance is another measure of inertial load (but it may also include other structural loads if static applied loads are applied or if structural parametric loads are applied).

For symmetric or antisymmetric half models, the "BALANCE" loads will not be zero since only half the vehicle is being summed. Rather than zeroing out the contribution (as is done for free flying stability derivatives), the imbalance is shown. These loads correspond to the structural boundary condition reactions at the "wind tunnel wall."

Output is shown in both body axes (i.e., the aerodynamic reference coordinate system) and in "wind" axes. Wind axes are defined such that the x-axis is aligned with the oncoming flow accounting for the trim angle of attack and sideslip angle. Since ANGLEA and BETA are the angle of attack and sideslip angle, the body axis velocity components can be derived from the following relations:

$$\alpha = atan\left(\frac{w}{u}\right)$$

$$\beta = asin\left(\frac{v}{V}\right)$$

where (u, v, w) are the body axis velocity components and V is the total velocity. Note that the angle of attack is not the rotation about the reference y-axis. An example FSW Airplane in Level Flight is provided (Refer to Figure 7-1).

Aerodynamic Pressures and Forces

This output table contains information on the pressures and forces on the aerodynamic elements at the trimmed flight condition. Both pressure coefficients and pressures are provided and one pressure per element is printed using the numbering convention for the j-set degrees of freedom described at the end of Aeroelastic Modeling. The aerodynamic "forces" are printed out in two columns, corresponding to the forces and moments acting on the panels at the aerodynamic grid points. The numbering convention for these k-set degrees of freedom can also be found at the end of Aeroelastic Modeling. Listing 7-24 contained in FSW Airplane with Bodies is particularly illustrative of this print in that it contains results for bodies as well as lifting surfaces. The body "pressures" are actually singularity magnitudes as defined by (2-5) and therefore do not have physical significance. Unit Solution for Loadings of the FSW Airplane present options that are available for using this print to obtain results for a particular aerodynamic extra point.

Standard Data Recovery

Once a trim analysis has been performed, structural displacements can be determined and standard MSC Nastran data recovery can be performed to provide output such as element stresses and forces and grid point displacements and SPC forces. Sample Output Listings in the *MSC Nastran Linear Static Analysis User's Guide* provides a description of this output.

Divergence Analysis

A divergence analysis produces two tables in the results file. An example of this output is given in Listing 5-1 for the input file discussed in Static Aeroelastic Analysis. The first table is the standard output from a complex eigenanalysis. Only roots that are purely imaginary and positive are physically meaningful. The second table therefore has screened the eigenvalues and prints them out in ascending magnitude of the divergence dynamic pressure, where

$$\bar{q}_p = -\lambda^2 \tag{5-1}$$

Listing 5-1

```
 EXAMPLE HA144B:  BAH JET TRANSPORT WING DYNAMIC ANALYSIS                                                  PAGE 19
  DIVERGENCE ANALYSIS

                                       C O M P L E X   E I G E N V A L U E   S U M M A R Y
                 ROOT     EXTRACTION                  EIGENVALUE                     FREQUENCY                 DAMPING
                  NO.        ORDER              (REAL)           (IMAG)               (CYCLES)               COEFFICIENT
                     1            2          -8.485735E+00     6.882407E-15              .0                      .0
                   2          1       -5.327813E-15     4.548029E+00         7.238412E-01           2.342911E-15
                   3          3       -5.993966E-16     9.788890E+00         1.557950E+00           1.224647E-16
                   4          4       -6.475911E-14     1.791923E+01         2.851933E+00           7.227891E-15
                   5          5        1.594443E-13     2.840956E+01         4.521522E+00          -1.122469E-14
                   6          6        1.362681E-13     5.442617E+01         8.662194E+00          -5.007446E-15
                   7          7        4.771999E+06     3.794945E+06         6.03984EE+05          -2.514924E+00
                   8          8       -3.616392E+05     6.943392E+06         1.105075E+06           1.041679E-01


 EXAMPLE HA144B:  BAH JET TRANSPORT WING DYNAMIC ANALYSIS                                                  PAGE 20
  DIVERGENCE ANALYSIS


 EXAMPLE HA144B:  BAH JET TRANSPORT WING DYNAMIC ANALYSIS                                                  PAGE 21
  DUVERGENCE ANALYSIS


          D I V E R G E N C E     S U M M A R Y

    MACH NUMBER =    .000000      METHOD = COMPLEX LANCZOS

    ROOT        DIVERGENCE                 EIGENVALUE
     NO.     DYNAMIC PRESSURE        REAL             IMAGINARY

      2         2.068457E+01    -5.327813E-15    4.548029E+00
      3         9.582236E+01    -5.993966E-15    9.788890E+00
      4         3.210987E+02    -6.475911E-14    1.791923E+01
      5         8.071033E+02     1.594443E-13    2.840956E+01
      6         2.962208E+03     1.362681E-13    5.442617E+01
```

Diagnostic Output

Certain MSC Nastran modules provide the ability to output additional information using "diagnostic" prints. Two examples of this that are relevant to static aeroelasticity are:

- DIAG 39 print aerodynamic box geometry information for ZONA51 aerodynamic panels inside the AMG module.
- DIAG 50 prints transformation information inside the ADG module. This was inserted during the development of this module, but is of limited utility to users.

Plots

MSC Nastran contains an internal plotter that provides minimal support for aeroelasticity. In the current engineering environment of graphical user interfaces, this capability is becoming obsolete. MSC Flighloads described in the *MSC Flightloads and Dynamic User's Guide* provide comprehensive support for pre and post processing of the MSC Nastran aeroelastic capability with an emphasis on static aeroelasticity. For static aeroelasticity, the geometry of the aerodynamic models can be displayed, including the meshing of the aerodynamic panels. This can be plotted in conjunction with the structural model so that it can be invaluable in identifying user input errors. Plotting in the *MSC Nastran Reference Guide* contains information of the use of the internal plotter. The AERO1 element identifies aerodynamic models for plotting purposes. FSW Airplane in Level Flight shows the Case Control requests required to produce the plot of the aerodynamic and structural model shown in Figure 5-1.

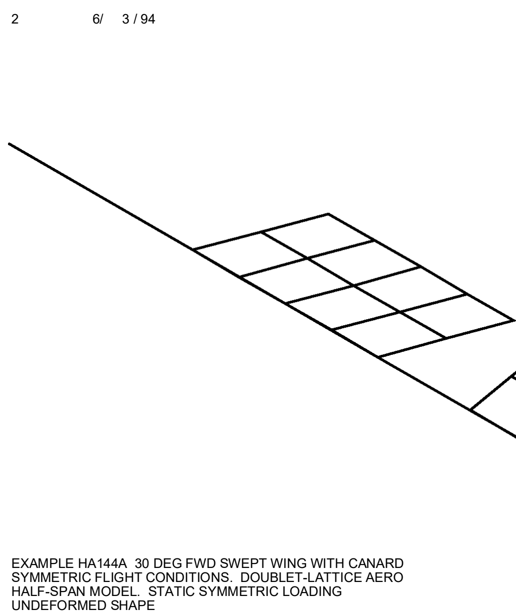


Figure 5-1 A Plot of the Forward-Swept-Wing (FSW) Airplane Aerodynamic and Structural Models Generated in the Example of Section 7.2 Using the MSC Nastran Internal Plotter

Flutter

Real Eigenanalysis

Eigenvalue results from the normal modes analysis are always printed while real eigenvector results are printed if the appropriate Case Control commands are present (SVEC for displacements in the a-set, DISP for global displacements). PARAM,OPPHIPA,1 can be used to output the eigenvectors at the aerodynamic grid points and can therefore assist in assessing the quality of the structural splining.

Flutter Summaries

A tabular listing is provided of the flutter results with each of the three flutter methods using a customized format. Listing 8-3 shows output for the PK- and K-methods applied to the same flutter analysis task. For the PK-method, roots are sorted in increasing frequency. POINT 1 then outputs the lowest frequency root at each of the velocities used in the flutter analysis and subsequent POINT's refer to the higher frequencies. If there are multiple densities and/or Mach numbers, `POINTS` corresponding to the first Mach number and density are printed first, followed by the (optional) second Mach number and first density and finishing with the final Mach number and final density. It is relatively easy to scan the damping column of a particular `POINT` to see if a branch is going unstable. Once a crossing is observed, the flutter velocity and frequency can be interpolated from the data that brackets the crossing.

K-method results are a bit more difficult to interpret. For this method, a `POINT` corresponds to a particular reduced frequency, Mach number, density triplet, with the data within the POINT arranged in increasing values of frequency. In this case, it is necessary to manually trace a flutter branch across POINTs to determine where a root goes unstable.

An example of a KE-method flutter summary is shown in Listing 8-16. For this method, a sorting algorithm, described in (2-170) and (2-171), is used to arrange the data in flutter branches, much like those already described above for the PK-method. The sorting algorithm is not robust so that sometimes branches become intertwined, but it is usually possible to untangle them using the plotted output of the V-g and V-f curves.

`PARAM,PRINT,NO` suppresses the print of the flutter summary. This can be used when V-g and V-f plots are relied upon to display the results of the flutter analysis.

Flutter Eigenvectors

Eigenvectors associated with the flutter eigenvectors are available for the PK and K methods of flutter analysis. An example of this output for the PK-method is given in Listing 8-3. The user indicates that eigenvectors are to be output for a particular velocity by entering a minus sign in front of that velocity on the `FLFACT` entry.

Two sets of eigenvectors are produced:

- **In modal coordinates**: That is, the eigenvector that is generated as part of the complex modal eigenanalysis). It appears prior to the flutter summary and is printed as the roots are extracted in the flutter analysis.
- **In physical coordinates**: That is, the eigenvector that results when the modal eigenvector is expanded to physical coordinates using the normal modes eigenvectors. It is generated and printed following the flutter analysis as a data recovery operation.

In both cases, the burden is on the user to connect the eigenvector with the particular flutter point by searching for the eigenvalue of interest. It is also possible to recover other responses, such as element stresses, for the eigenvectors.

An example of flutter eigenvectors produced by the K-method is also given in Listing 8-3. The `OFREQUENCY` Case Control command can be used to restrict the range of frequencies over which eigenvector results are output.

Diagnostic Output

As in the static aeroelastic description above, DIAG 39 produces aerodynamic box geometry information for ZONA51 aerodynamic modules inside the AMG module. It also provides detailed information on the PK-method of flutter analysis that provides a history of the iterations used to produce the Flutter Summary results.

Plots

As in static aeroelasticity, the geometry of the aerodynamic models can be displayed, including the meshing of the aerodynamic panels. In addition, the real eigenvectors can be displayed on the aerodynamic model if PARAM,OPPHIPA,1 has been used. Only the VECTOR option can be used for these displacements.

V-g and V-f plots may be requested by the XYOUT Case Control commands by specifying the curve type as VG. The *points* are loop numbers and the *components* are g (structural damping), or f (frequency). An example of these plot requests can be found in Listing 8-5. The first plots produced by this request are displayed in Figure 5-2.

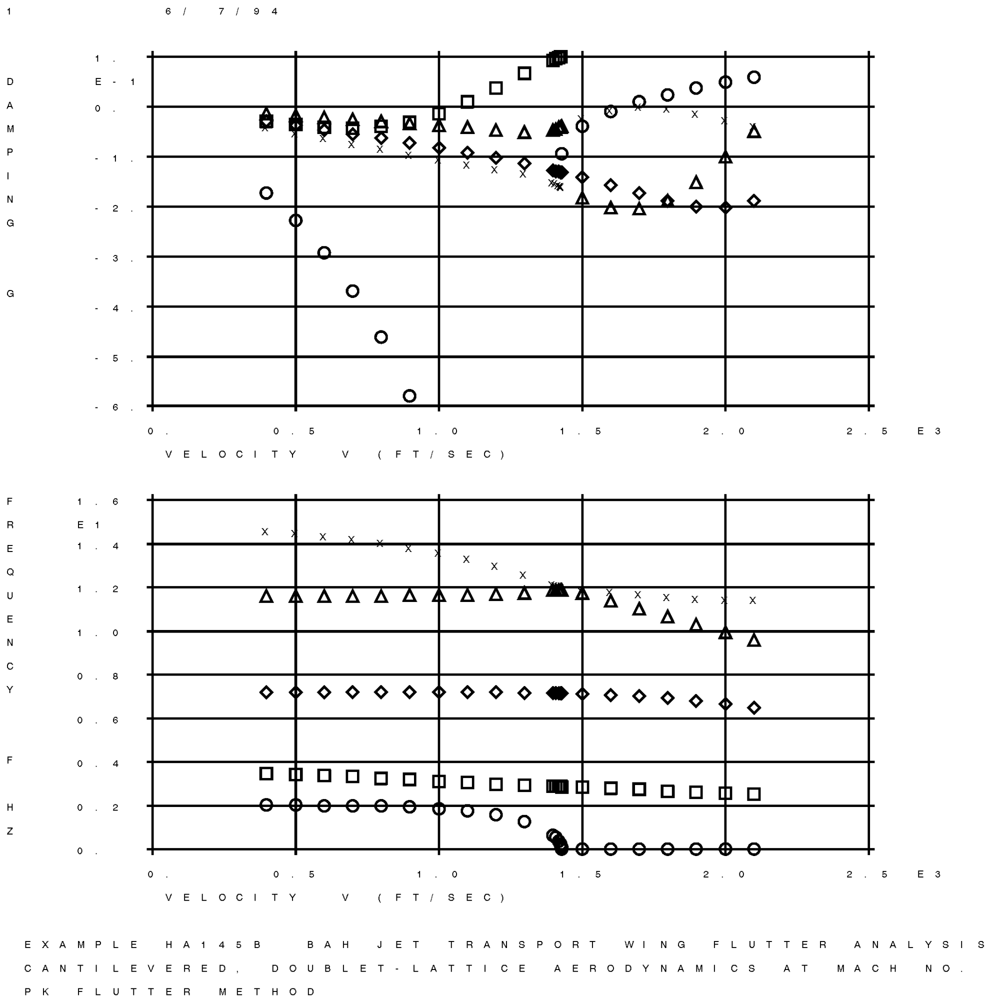


Figure 5-2 A V-g, V-f Plot Generated from the Example Contained in Section 8.3 Using the MSC Nastran Internal Plotters

Dynamic Aeroelasticity

Output for Dynamic Aeroelastic Response Analysis

Output, sorted by point number or element number (SORT2), is available either as real and imaginary parts or magnitude and phase angle (0° to 360°) for the list of frequencies specified by the OFREQUENCY Case Control command. For transient problems, real numbers are output at the list of times specified by the OTIME Case Control command.

Transient and Frequency Response

The following data may be printed in transient and frequency response outputs analysis:

- Displacements, velocities, and accelerations for a list of physical points (grid points and scalar points introduced for dynamic analysis) or for solution points (points used in formulation of the matrices in the general equations of motion).
- Nonzero components of the applied-load vector and single-point forces of constraint for a list of grid points and extra points.
- Aerodynamic pressures and forces on selected aerodynamic elements.
- Stresses and forces on selected elements (= ALL, which specifies all elements, is available only for `SORT2`).

Random Response

The following printed output is available for random response calculations:

- The power spectral density function and the root mean square value of the response of listed components for points or elements.
- The expected number of zero crossings with positive slope per unit time, N0.
- The auto correlation function of the response of listed components for points or elements.

Plots

The following plotter output is available for dynamic aeroelastic response analyses:

- Undeformed plot of the structural model.
- XY-plot of any component of displacement, velocity, or acceleration of a list of points versus time or frequency.
- XY-plot of any component of the applied-load vector or single-point force of constraint versus time or frequency.
- XY-plot of any stress or force component for an element versus time or frequency.

The following additional plotter output is available for random response analyses:

- XY-plot of the power spectral density versus frequency for the response of listed components for points or elements.
- XY-plot of the auto correlation versus time delay for the response of listed components for points or elements.

The data specified for the XY-plots may also be punched or printed in tabular form. See Plotting (p. 467) in the *MSC Nastran Reference Guide*. Also, a summary is printed for each XY-plot that includes the maximum and minimum values of the plotted function.

Design Sensitivity And Optimization

For aeroelastic optimization tasks, `PARAM,NASPRT` can be quite useful. This parameter indicates how frequently results are printed during the design task. Since these results can be extensive, using the default will minimize the number of pages and output that is produced. For a comprehensive description of the output from SOL 200, refer to Output Features and Interpretation in the Design Sensitivity and Optimization User's Guide.

6 Aeroelastic Solution Sequences

Overview

As discussed in Executive Control Section, the standard use of MSC Nastran requires a solution sequence, and there are four solution sequences that relate to aeroelasticity:

SOL Number	SOL Name	Description
144	AESTAT	Static Aeroelasticity
145	SEFLUTTR	Aeroelastic Flutter
146	SEAERO	Dynamic Aeroelasticity
200	DESOPT	Design Sensitivity and Optimization

This chapter briefly describes the functionality of each of these solution sequences. Some users require a more in-depth understanding to the solution sequences; for example, to extract intermediate results or to alter the solution sequence to provide functionality not provided in the basic sequence. For this reason, the remainder of the chapter provides significant detail on the solution sequences. This includes a description of the key subDMAPS, brief descriptions of each of the modules, and a listing of key data blocks.

Solution Sequence Functions

Static Aeroelasticity

The static aeroelastic solution sequence (SOL 144) provides the following capabilities:

- The user supplies finite element models for the definition of the structure and aerodynamic loading, including information on the flight condition. The loads and accelerations are assumed to be independent of time that is, quasi-steady.
- Stability and control derivatives are printed for each unique flight condition (Mach number and dynamic pressure). Derivatives are printed for the rigid vehicle and for the restrained and unrestrained elastic vehicles.
- A trim analysis is performed that determines unknown trim values and then performs standard data recovery for each TRIM subcase defined in the Case Control section of the input data file. Aerodynamic forces and pressures on the aerodynamic elements may be obtained via the AEROF and APRES Case Control commands, respectively.
- Three matrices are available for altering the theoretically predicted aerodynamics. Correction factors can be input using WKK, experimental pressures can be input using FA2J and adjustments to the downwash to account for, for example, the effects of camber and twist, can be input using matrix W2GJ.
- A static aeroelastic divergence analysis is available by specifying a DIVERG Case Control command in a subcase. The divergence analysis is performed at the Mach numbers specified on the corresponding DIVERG Bulk Data entry.

Any of the aerodynamic methods can be utilized for divergence analysis. Strip Theory, the Mach Box method, and Piston Theory are not available for trim and stability analysis.

Flutter Analysis

The flutter solution sequence (SOL 145) provides a comprehensive flutter analysis with the following capabilities:

- The user supplies finite element models for the definition of the structure and the aerodynamic model. Aerodynamic matrices are computed explicitly at each of the user-supplied Mach number and reduced frequency combinations.
- A modal analysis is always performed. Changes in the mass and stiffness matrices may be made subsequent to the modal analysis via DMIG Bulk Data entries.
- Control systems can be modeled using extra point, transfer function and DMIG inputs. The user can supply downwash vectors for extra point motions using the DMI matrices D1JE and D2JE.
- A flutter analysis is performed based on the parameters specified on the FLUTTER Bulk Data entry that is selected by the FMETHOD Case Control command. The K- and KE-methods compute flutter roots for user-specified values of density, Mach number and reduced frequency. The PK-method extracts these roots for user-specified values of density, Mach number and velocity.
- Multiple subcases can be specified. This enables the use of, for example, different flutter solutions or multiple sets of DMIG information.
- A flutter summary is printed and (optionally) V-g and V-f plots are produced.
- Data recovery can be performed on the flutter eigenvectors produced for the K- and PK-flutter solutions.

All MSC Nastran aerodynamic theories are available and more than one aerodynamic theory can be present in the same aerodynamic model.

Dynamic Aeroelasticity

The dynamic aeroelasticity solution sequence (SOL 146) provides analysis capability in the time or frequency domain. The following capabilities are available:

- The user supplies finite element models for the structure and the aerodynamics. Aerodynamic matrices, including gust loads, are computed at each of the user-specified Mach number and reduced frequency combinations.
- Frequency or time-dependent loading can be specified. Time varying loads are converted to the frequency domain using ad hoc Fourier transform techniques. For details, see Dynamic Aeroelastic Analysis. The excitation can be aerodynamic (such as gust loading), or external (such as mechanical loads representing store ejection or landing loads).
- A modal analysis is always performed. Changes in the mass and stiffness matrices may be made subsequent to the modal analysis via DMIG Bulk Data entries.
- Control systems can be modeled using extra point, transfer function, and DMIG inputs. The user can supply downwash vectors for extra point motions using DMI matrices D1JE and D2JE.

- Basic computations are always performed in the frequency domain. If input is provided in the time domain, an inverse Fourier transform is used to provide output in the time domain.
- The modal participation type of data recovery is used. The internal loads or stresses are found in each mode and the response loads are found from the linear combination of the products of the loads in each mode and its amplitude. This method of internal load response calculation is called the "Modal Displacement Method" in Bisplinghoff, Ashley, and Halfman (1955, pp 641-650) [Reference 8].
- Output can be displacements (including velocities and accelerations), stresses, or constraint forces. XY-plots are available. Aerodynamic data (pressures and forces) are also available with frequency response analysis.
- Random response analysis obtains power spectral density, root mean square response, and mean frequency of zero crossings.

All MSC Nastran aerodynamic theories are available for calculating the dynamic aeroelastic response to external loading. The Strip, Mach Box, and Piston Theory aerodynamics are not available for gust loads.

Design Sensitivity and Optimization

The design sensitivity and optimization solution sequence (SOL 200) contains multidisciplinary analysis and design capabilities that are beyond the scope of the this guide. The reader is referred to the companion *Design Sensitivity and Optimization User's Guide* for a focused discussion of SOL 200. For the purposes of this guide, the aeroelastic capabilities are summarized in this section:

- The full range of static and flutter analysis capabilities of SOLs 144 and 145 are available in SOL 200.
- Sensitivity of analysis responses with respect to changes in properties of the structural finite element model can be computed. For static aeroelastic analyses, these responses include not only standard displacement and stress responses, but also sensitivities of stability derivatives and trim variables. For flutter, the sensitivity of the damping levels computed in a PK-flutter analysis are available.
- Multidisciplinary optimization enables the simultaneous consideration of responses from any number of disciplines in order to formulate a structural design that minimizes a user-defined quantity, such as vehicle weight, while satisfying imposed design conditions (for example, requirements on stress, roll performance, and flutter stability).

Although all of the SOL 144 and 145 analysis capabilities are available in SOL 200, a subset of these capabilities is available for sensitivity and optimization. For flutter, only the PK-method of analysis can be used in flutter design.

Solution Sequence Structure

This section provides an overview of the solution sequences related to aeroelasticity by discussing the underlying subDMAPs. It is beyond the scope of this guide to provide a comprehensive treatment of the DMAP listings.

Structured solution sequences are composed of a main driver subDMAP, which can invoke any number of additional subDMAPs. Figure 6-1, Figure 6-2, and Figure 6-3 show the high-level structure of subDMAPs `AESTAT`, `SEFLUTTR`, and `SEAERO`, which are the drivers for SOLs 144, 145, and 146, respectively.

In the figures, the items in boxes are subDMAPs and the shaded boxes are the key aeroelastic subDMAPs and are discussed further in this section.

It is seen that there is a great deal of commonality among the sequences. The shared and nonshaded subDMAPs include:

- `SUPER1`: Performs initial processing extending from input file processing through the assembly of the global matrices.
- `SUPER3`: Solution vector data recovery.

The following subDMAPs are only used in modal solutions (SOLs 145 and 146):

- `OPPH`: Processes normal modes for data recovery and plots.
- `GMA`: Converts physical matrices into modal coordinates.
- `VDR1`: Processes xy plot and solution set requests.
- `MODACC`: Selects vectors for further postprocessing.
- `MODERS`: Performs normal modes analysis.

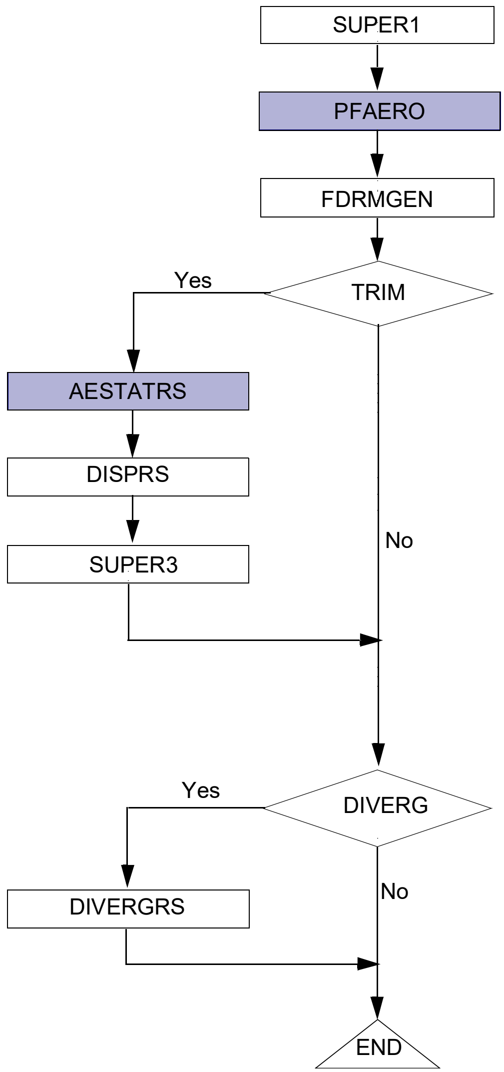


Figure 6-1 Solution Sequence 144 (Static Aeroelasticity). The driver subDMAP is AESTAT

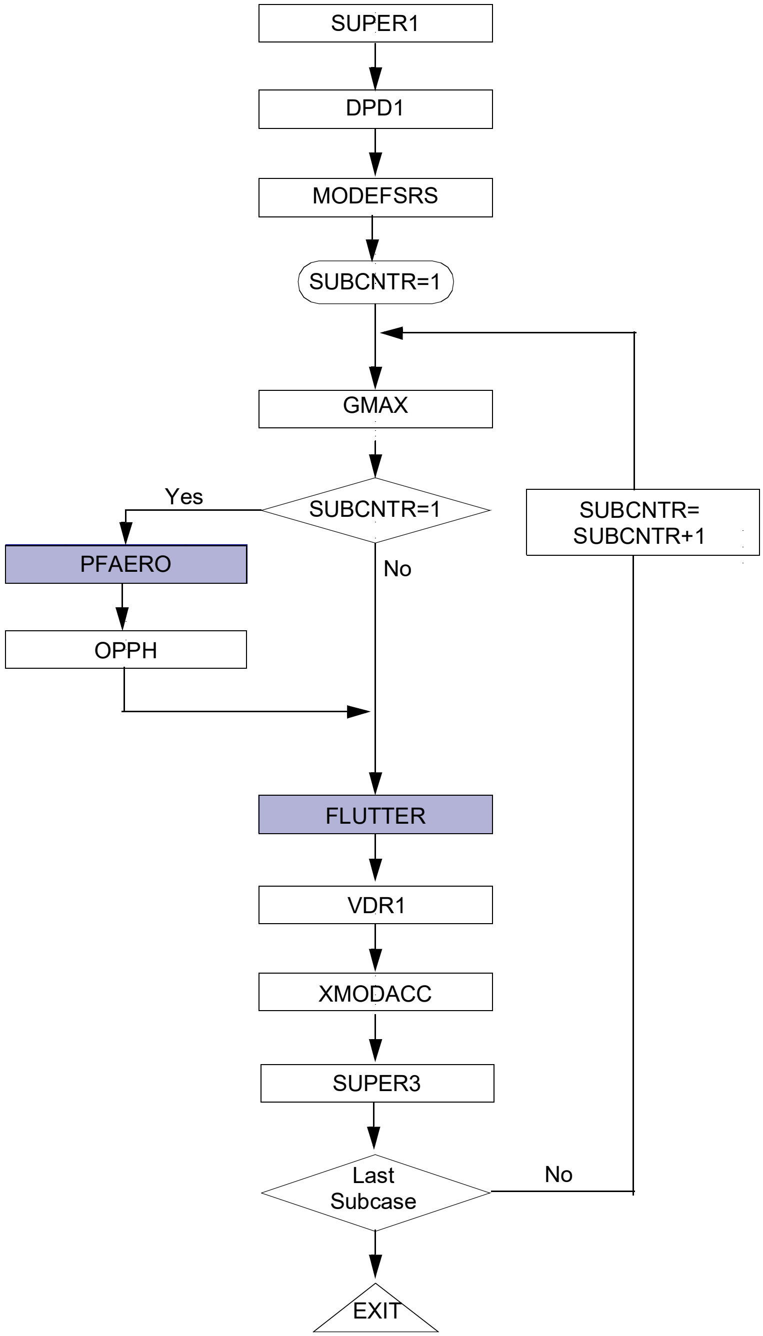


Figure 6-2 Solution Sequence 145 (Aerodynamic Flutter). The driver subDMAP is SEFLUTTR

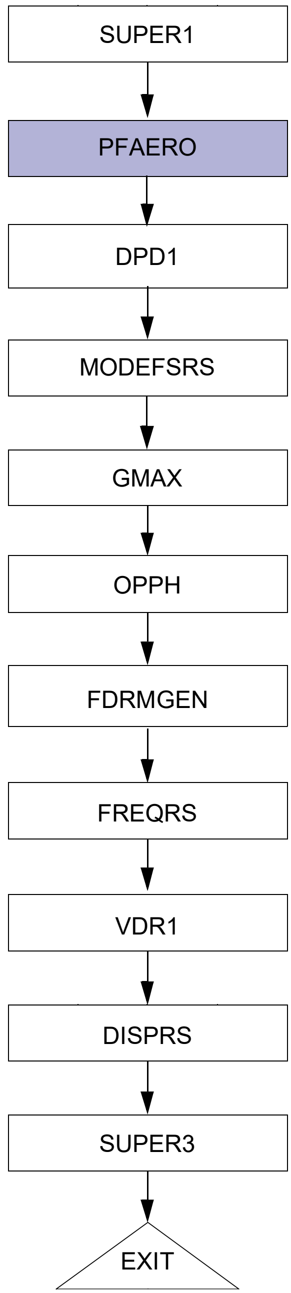


Figure 6-3 Solution Sequence 146 (Dynamic Aeroelasticity). The driver subDMAP is SEAERO

Shaded subDMAPs shown in Figure 6-1 through Figure 6-3 plus aeroelastic sensitivity subDMAPs are identified in Table 6-1 with the remainder of this subsection devoted to discussion of each. The discussions are meaningful only if a listing of the subDMAP is available. A complete solution sequence listing may be obtained making a MSC Nastran run with DIAG 14 set in the Executive Control Section of the input data file. This will list the complete solution sequence. If only a particular subDMAP, for example, PFAERO, is of interest, this can be obtained with the following Executive Control Command:

```
COMPILE PFAERO LIST
```

Table 6-1 Aeroelastic SubDMAPs

SubDMAPS	Solution Sequence				Function
	144	145	146	200	
PFAERO	X	X	X	X	Performs preface aerodynamics calculations
AESTATRS	X			X	Statics aeroelastic analysis
FLUTTER		X		X	Flutter analysis
DESAERDR				X	Generates output solution vectors for static aeroelastic sensitivity analysis
SAERSENS				X	Performs static aeroelastic sensitivity analysis

PFAERO

This subDMAP performs all processing of the aerodynamic data that is independent of the structural model, plus it generates the global spline matrix. The steps involved are:

1. Read in any DMI input (**DMIIN**).
2. Determine which aerodynamic methods are present.
3. If only unsteady results are required, go to step 16.
4. Form static aeroelastic matrices that are only a function of geometry (**ADG**).
5. Loop on the number of static aeroelastic subcases.
6. Loop on the number of Mach numbers per subcase. For trim analysis, this number is one. For divergence analysis, this is the number of Mach numbers appearing on the DIVERG Bulk Data entry.
7. Determine Mach number of the current pass (**AELOOP**).
8. If the aerodynamic data are already present for this Mach number, go to step 6.
9. Generate aerodynamic matrices (**AMG**).
10. Apply weighting factors, if any. $[WSKJ] = [WKK][SKL]$.
11. For divergence analysis, it is possible to mix aerodynamic methods. For brevity, the description of the portion of the subDMAP that enables this capability is not provided.
12. Decompose RAJJT to LAJJ, UAJJ
13. Next Mach number.

14. Next subcase.
15. If only steady results are required, go to step 24.
16. Determine if aerodynamic matrices are to be generated (**PARAML**).
17. Loop on the number of Mach number, reduced frequency pairs.
18. Determine Mach number and reduced frequency.
19. If the required aerodynamic data are already present for this condition, go to step 23.
20. Compute aerodynamic matrices (**AMG**).
21. Decompose AJJT to LAJJT, UAJJT
22. It is possible to mix aerodynamic methods. For brevity, the lengthy DMAP code that enables this capability is not described.
23. Process the next Mach number and reduced frequency.
24. Return.

AESTATRS

This subDMAP performs the basic static aeroelastic operations as outlined in Static Aeroelasticity. It is a complex process that has been optimized to perform well when being used to handle many hundreds of subcases that account for multiple boundary conditions, subcase dependent mass, and varying Mach numbers and dynamic pressures. A very high level description is given here while the actual subDMAP has extensive statements to deal with subjects such as monitor points, rigid/flexible aerodynamics, support for modal solutions and aerodynamic databases. The user's case control is looped through five times with each loop performing specialized operations as detailed below.:

1. Invariant matrices related to rigid body and monitor point calculations are generated (SAERG1).
2. The first case control loop computes structural matrices such as TR that are independent of the aerodynamics.
3. The second loop provides rigid aerodynamics for each unique Mach, dynamic pressure and mass set.
4. The third loop provides aeroelastic increment loads for each unique Mach and dynamic pressure
5. The fourth loop computes the elastic part of the solutions.
6. The fifth and final loop goes through all the subcases and performs the requested trim operations based on the components assembled in the previous loops. Notable computations include:
   a. Invoking the SDP module to perform stability derivative calculations.
   b. Invoking the ASG module to perform trim calculations.
   c. Outputting the subcase results, including trim results, monitor points, any CSV requested data and append the solution for further post processing by standard MSC Nastran data recovery.

DIVERGRS

This subDMAP performs static aeroelastic divergence analysis. The steps involved are:

1. A matrix transform is performed on a spline matrix: $[GKL] = [GTKL]^T$
2. A loop is begun on the number of subcases.
3. Determine if this is a divergence subcase (**PARAML**).
4. If there are no more subcases, RETURN. If this is not a divergence subcase, go to step 16.
5. Begin a loop on the number of Mach numbers found on the DIVERG Bulk Data entry for this subcase.
6. Extract the Mach number (**AELOOP**).
7. Check for the presence of the $[QLL]$ matrix for this Mach number.
8. If the $[QLL]$ matrix is not present, form $[QLL] = [GKL]^T[QKK][GKL]$.
9. Determine the eigenvalues and eigenvectors of $[KLL + \lambda QLL]$ (**CEAD**).
10. Form $[QLL]^T$ and repeat the complex eigenanalysis.
11. Print the eigenvalues of the complex eigenanalysis.
12. Print any user-requested right-hand eigenvectors.
13. Print the divergence results.
14. Append results from this subcase to previously computed results.
15. Go to step 17.
16. Increment the subcase counter.
17. Go to step 2.
18. Copy results to the database.
19. Return.

FLUTTER

The FLUTTER subDMAP performs the flutter analysis. The subDMAP is called inside a subcase loop from the SEFLUTTR main driver for SOL 145. The driver performs operations to generate the structural generalized matrices, including subcase dependent masses. It performs a normal modes analysis and calls PFAERO to generate the basic aero matrices. For each subcase in seflutter:

1. SUBCNTR is incremented by one. NSKIP is set to -1 if this is the last subcase.
2. Perform the operations described above
3. Call the FLUTTER subDMAP
4. If this is not the first subcase for the current boundary condition, step 12.
5. Combine modes and spline matrices to create GPIK and GDIK
6. Loop on the number of Mach numbers and reduced frequency
7. Set Mach number and reduced frequency qualifiers.

8. Call AMP to form generalized aerodynamic matrices
9. Append general aero matrices using a special append feature of the SDR1 module.
10. Next Mach number and reduced frequency
11. Generate matrix lists [QHHL} and [QKHL] using MATMOD, option 22
12. Loop on the flutter analysis triplets
13. For the PK- or KE-methods, perform the required flutter analyses. For the K-method, set up the matrices for the complex eigensolver (FA1).
14. For the PK- and KE-methods, equivalence FA1 outputs [KXHH] and [BXHH] to eigenvector and eigenvalue data blocks, respectively, and go to step 16.
15. For the K-method, perform the complex eigenanalysis (**CEAD**).
16. Transfer the flutter results to output data blocks (**FA2**).
17. Go to step 12.
18. Copy data to the database.
19. If requested, form V-g and V-f plots (**XYTRAN** AND **XYPLOT**).
20. If requested, print out aerodynamic forces for the flutter eigenvectors (**ADR**).
21. Return to SEFLUTTR.
22. If there are no flutter eigenvectors, go to step 26.
23. Go to subDMAP VDR1 to process any solution set requests.
24. Go to subDMAP MODACC to extract out eigenvectors requested for further processing.
25. Go to subDMAP SUPER3 to process user requests for eigenvectors in physical degrees of edom.
26. If NSKIP is positive, go to step 1.
27. END.

DESAERDR

This subDMAP performs specialized matrix operations required in the computations of static aeroelastic sensitivities. The output of the subDMAP is three a-set size matrices that contain (1) all the displacement vectors required in performing aeroelastic sensitivity analysis (AUADS), (2) all the acceleration vectors required in performing aeroelastic sensitivity analysis (AAADS), and (3) the subset of the displacement vectors that is required in the sensitivity analysis for unrestrained stability derivatives (UUADS). The steps in the subDMAP are:

1. Matrix $[RFSOP] = [TR]^T[TRX]$ is formed and counters for the number of columns in AUADS (NSOL) and UUADS (NMSOL) are initialized to zero.
2. A loop on the number of records in the Case Control data block and that terminates at step 20 is initiated.

3. A determination is made as to whether the sensitivity is required for static responses (STFLG > 0), trim responses (TFLG > 0) and/or stability derivatives (SDFLG > 0). For SDFLG > 0, [UXU] contains pseudotrim vectors for determining unrestrained stability derivative sensitivities, and UXR contains pseudotrim vectors for determining restrained stability derivative sensitivities (**DSARLP**).
4. If none of the above flags is set, go to step 2.
5. The Mach number and dynamic pressure qualifiers are set for the subcase.
6. Form: $[ALX] = [KSALL]^{-1}[KALX]$.
7. If STFLG = 0 and TFLG = 0, go to step 11
8. Extract the a-set accelerations and the l-set displacements vector for the current subcase from the respective matrices created in AESTATRS (**MATMOD**).
9. Expand the displacement vector to the a-set (**UMERGE**).
10. Append the vector onto the scratch output data blocks and increment NSOL by one.
11. If $[UXU]$ is not present, go to step 16.
12. Increment NMSOL and NSOL by the number of columns in $[UXU]$.
13. Repeat a number of analysis calculations to create data blocks required for the sensitivity analysis. See the Unrestrained Stability Derivatives for a description of these operations.
14. Recover a-set displacements $[UAP]$ and accelerations $[UADDP]$ for the $[UXU]$ vector based on

$$
\begin{aligned}
&[KRAX] = -[KR1ZX][UXU] \\
&[URDDP] = -[MIRR][KRAX] \\
&[URP] = -[M4RR][URDDP] - [KRLX][UXU] \\
&[TMP2] = [AMLR][URDDP] + [ARLR][URP] \\
&[ULP] = [ALX][UXU] - [TMP2]
\end{aligned}
$$

$[UAP]$ is formed by a merge of $[URP]$ and $[ULP]$.

15. $[UAP]$ is appended onto both $[AUADSX]$ and $[UUADSX]$. $[URDDP]$ is appended onto $[AAADSX]$.
16. If $[UXR]$ is not present, go to step 20.
17. Increment NSOL by the number of columns in $[UXR]$.
18. Recover a-set displacements $[UAR]$ and accelerations $[AAR]$ for the $[UXR]$ matrix based on:

$$[ARR] = [RFSOP][UXR]$$
$$[ALR] = [DM]^T[ARR]$$

$[AAR]$ is formed by a merge of $[ALR]$ and $[AAR]$

$$[PLXR] = -[MSLR][ARR] - [KALX][UXR]$$
$$[ULR] = [KSALL]^{-1}[PLXR]$$

$[UAR]$ is formed by a merge of $[ULR]$ and a purged matrix representing zero displacement in the r-set.

19. $[UAR]$ is appended onto $[AUADSX]$ while $[AAR]$ is appended onto $[AAADSX]$.
20. Go to step 2.
21. Scratch output data blocks are equivalenced to data blocks stored on the database.
22. Return.

SAERSENS

This subDMAP creates sensitivities of static aeroelastic displacements $[AULDS]$, trim variables $[DELX]$, and stability derivatives $[DELS]$. The steps involved are:

1. The rigid body matrix $[DALR]$ and $[RFSOP]$ matrix are formed.
2. $NCOL$, the number of displacement and acceleration vectors, $NMCOL$, the number of pseudodisplacement vectors, and NDV, the number of design variables, are determined.
3. A loop that terminates at step 35 is initiated on the number of records in the Case Control data block.
4. A determination is made as to whether sensitivity analysis is required for static responses ($STFLG > 0$), trim responses ($TFLG > 0$), and/or stability derivatives ($SDFLG > 0$). For $SDFLG > 0$, $[UXU]$ contains pseudotrim vectors for determining unrestrained stability derivative sensitivities, and $[UXR]$ contains pseudotrim vectors for determining restrained stability derivative sensitivities (**DSARLP**).
5. If $STFLG$ and $TFLG$ are both zero, construct a null matrix all with l-size rows and NDV columns and append it to $LAULAX$.
6. If all of the $DSARLP$ flags are zero, go to the next subcase (step 3).
7. Set Mach number and dynamic pressure qualifiers.
8. Form: $[KAZR] = [DM]^T[KALR] + [KARR]$.

9. If $STFLG$ and $TFLG$ are zero, go to step 16.
10. Create a partitioning vector to cut out the required pseudoloads from the $[PA]$ matrix (**MATGEN**, option 4).
11. Partition out the vectors into matrix $[DPSAA]$ and equivalence the remaining columns to $[PA]$.
12. Partition the a-set loads to the l-set and solve for the pseudodisplacements:

$$[DUAL] = [KSALL]^{-1}[DPSAL]$$

13. Create trim pseudoloads:

$$[DPZ] = -[KAZL][DUAL] + [DALR]^{-1}[DPSAA]$$

14. Solve for $[DUX]$, the perturbed trim variables (**ASG**).
15. Recover $[DUL]$, sensitivity displacements in the l-set:

$$\begin{bmatrix} [DKSALX] = -[KALX][DUX] + [DPSAL] \\ [DPLX] = -[MSLR][RFSOP][DUX] + [DKSALX] \\ [DUL] = [KSALL]^{-1}[DPLX] \end{bmatrix}$$

16. The sensitivity vectors are appended onto a scratch output data block.
17. If $[UXU]$ is absent, go to step 23.
18. Recreate some $AESTATRS$ data blocks that were not stored (see Static Aeroelasticity).
19. Create a partitioning vector to cut out the required pseudoloads from the $[PA]$ matrix (**MATGEN**, option 4).
20. Partition out the vectors into matrix $[DPSAAU]$ and equivalence the remaining columns to $[PA]$.
21. Create a partitioning vector to cut out the required pseudoloads due to mean axis deformations from the PMA matrix (**MATGEN**, option 4).
22. Partition out the vectors into matrix $[DPSAUM]$ and equivalence the remaining columns to $[PMA]$.
23. A series of matrix algebra statements is now executed to form matrix $[DSTABU]$, a matrix of dimensional unrestrained stability derivative sensitivities. Static Aeroelastic Sensitivity contains a description of these operations in the notation used in this subDMAP.
24. If $[UXR]$ is absent, go to step 28.

25. Create a partitioning vector to cut out the required pseudoloads from the $[PA]$ matrix (**MATGEN**, option 4).
26. Partition out the vectors into matrix $[DPSAR]$ and equivalence the remaining columns to $[PA]$.
27. Remove the r-set degrees of freedom from $[DPSAR]$ with the result placed into $[PLSTBL]$.
28. Form the dimensional restrained stability derivative matrix:

$$[DSTABR] = -[KAZL][KSALL]^{-1}[PLSTABL]$$

29. The information contained in matrices $[DUX]$, $[DSTABR]$, and $[DSTABU]$ is extracted and converted into matrices $[DELX1]$ and $[DELS1]$. $[DELX1]$ contains sensitivities for the user-requested trim variables while $[DELS1]$ contains sensitivities for all the user-requested stability derivatives. (**DSARSN**)
30. If this is the first subcase to generate $[DELS1]$, equivalence $[DELS1]$ to $[DELS2]$ and go to step 31.
31. Merge matrices $[DELS1]$] and $[DELS2]$] into $[DELSX]$ and equivalence $[DELSX]$ to $[DELS2]$.
32. If this is the first subcase to generate $[DELX1]$, equivalence $[DELX1]$ to $[DELX2]$ and go to step 33.
33. Merge matrices $[DELX1]$ and $[DELX2]$ into $[DELXX]$ and equivalence $[DELXX]$ to $[DELX2]$.
34. Go to step 3.
35. Scratch data blocks $[DELX2]$ and $[DELS2]$ are equivalenced to NDDL data blocks $[DELX]$ and $[DELS]$.
36. Scratch data block $[LAULDX]$ contains sensitivity vectors for multiple subcase and multiple design variables. Further processing of these vectors require that all the vectors for a given design variable be contiguous. A do loop on the number of design variables rearranges the vectors that have all vectors for a given subcase contiguous into the required order and places the results in scratch data block $[AULDSX]$.
37. $[AULDSX]$ is equivalenced to $NDDL$ data block $[AULDS]$.
38. Return.

Aeroelastic Modules

The following modules are unique to aeroelasticity. The *MSC Nastran DMAP Programmer's Manual* contains short description of these modules.

ADG	The Aerodynamic Downwash Generator calculates the downwash matrix, which specifies the downwash for each of the aerodynamic extra points. It also forms matrices required in the generation of stability derivative information and in the specification of the aerodynamic trim equations.
ADR	Aerodynamic Data Recovery builds a matrix of aerodynamic forces per frequency for each aerodynamic point. The data are output for a user-selected set.
AELOOP	Aeroelastic Loop extracts a single record of Case Control and sets up values that drive the subsequent DMAP instructions for the generation of aerodynamic matrices and/or the performance of static aeroelastic analyses.
AMG	The Aerodynamic Matrix Generator generates aerodynamic influence matrices (AJJT) and the transformation matrices needed to convert these to the interpolated structural system (SKJ, D1JK, D2JK).
AMP	Generates aerodynamic modal matrices including QHH, QKH and QHJ.
APD	The Aerodyanmic Pool Distributor generates aerodynamic "boxes" for all aeroelastic solutions. Tables are assembled to account for the "box" coordinates.
ASDR	The Aeroelastic Static Data Recovery module prints the aerodynamic extra point displacements and the aerodynamic pressures and forces as requested in the Case Control Section.
ASG	The Aerodynamic Solution Generator solves for the aerodynamic extra point displacements.
DIVERG	The Divergence module determines which of the complex eigenvalues extracted in CEAD are physically meaningful and performs a formatted print of the divergence information. It performs a partition of the eigenvectors, saving the eigenvectors that correspond to the divergence roots.
DSARLP	This module calculates pseudodisplacements that are to be used in the calculation of the sensitivities of stability derivatives. It also determines parameters that are required for all static aeroelastic sensitivity analyses.
DSARSN	Calculates and stores delta response values for trim variables and stability derivatives.
DSFLTE	This module calculates right and left eigenvectors for eigenvalues that have been extracted in a flutter analysis and have been flagged for sensitivity analysis.
DSFLTF	This module calculates the sensitivity of active flutter responses.
FA1	The FA1 module prepares the modal matrices MXHH, BXHH, and KXHH for the K-method of eigenvalue analysis or does the complete eigenvalue analysis for the KE- or PK-method.
FA2	The FA2 module collects aeroelastic flutter data for reduction and presentation for each triplet of the configuration parameters.
GI	The Geometric Interpolation module generates the transformation matrix from structural to aerodynamic displacements.

IFT	The Inverse Fourier Transform module obtains solutions as a function of time for aeroelastic problems for which the aerodynamic forces are only known as functions of frequency.
SDP	The Stability Derivative Printer module calculates and prints the nondimensional stability and control derivatives.

Selected Aeroelastic Data Blocks

The data blocks listed in this section are of particular interest in aeroelasticity. These data blocks have been chosen from a much larger set because they contain the key data that are most likely to be of interest to the user. The module that creates the particular data block is noted at the end of each brief description.

Aerodynamic Model and Spline Information

ACPT	Aerodynamic Connection and Property Table. Contains CAEROi, PAEROi, and AEFACT inputs after they have been preprocessed (APD).
AERO	Aerodynamics matrix generation data. Contains AERO and MKAEROi inputs after they have been preprocessed (APD).
EDT	Element Deformation Table. This table contains all Bulk Data entries related to aeroelasticity (IFP).
GTKG	Aerodynamic transformation matrix. $\{u_g\} = [GTKG]\{u_k\}$, $\{F_g\} = [GTKG]^T\{F\}$. The matrix has as many rows as there are degrees of freedom in the g-set and as many columns as there are degrees of freedom is the k-set (GI).
SPLINE	Contains SPLINEi inputs after they have been preprocessed (APD).

Static Aeroelastic Geometry

DJX	Downwash matrix. Downwash at the aerodynamic grid points due to motion of an aerodynamic extra point (ADG).
SRKT	Aerodynamic summation matrix. Sums forces acting at the aerodynamic degrees of freedom to the aerodynamic reference point (ADG).
TR	Transformation matrix. Transforms forces from the SUPORT degrees of freedom to the aerodynamic reference point (ADG).
TRX	Acceleration selection matrix. A Boolean matrix to select accelerations from the list of aerodynamic extra points (ADG).
XLIST	Extra point list table. Contains AESTATRS and AESTAT inputs after they have been preprocessed (ADG).

Aerodynamics Matrices

AJJT	Aerodynamic influence coefficient matrix. For Doublet-Lattice and ZONA51 aerodynamics, the transpose of this matrix computes the downwash on the aerodynamic elements for a specified pressure vector. For Strip, Mach Box, and Piston Theories the matrix computes the pressure on the aerodynamic elements for a specified downwash vector. This matrix is for unsteady flows and is therefore complex (AMG).
D1JK	Real part of the substantial differentiation matrix. This matrix, when combined with D2JK, computes the downwash at the aerodynamic control point due to deflections of the aerodynamic degrees of freedom. (AMG).
D2JK	Imaginary part of the substantial differentiation matrix (see D1JK above). This matrix is not required for the static aeroelastic analysis (AMG).
QKJ	Gust aerodynamic influence coefficient matrix. Computes forces on the degrees of freedom in the k-set due to downwashes at the aerodynamic control points. This matrix is for unsteady flows and is therefore complex (PFAERO subDMAP).
QKK	Aerodynamic influence coefficient matrix. Computes forces on the degrees of freedom in the k-set due to displacements at the k-set degrees of freedom. This matrix is for unsteady flows and is therefore complex (PFAERO subDMAP).
QKKS	Steady aerodynamic influence coefficient matrix. Computes forces on the degrees of freedom in the k-set due to displacements at the k-set degrees of freedom. This matrix is for steady flows and is therefore real (PFAERO subDMAP).
QKX	Steady aerodynamic influence coefficient matrix for aerodynamic extra points. Computes forces on the degrees of freedom in the k-set due to displacements of the aerodynamic extra points. This matrix is for steady flows and is therefore real (PFAERO subDMAP).
RAJJT	Same as AJJT for steady aerodynamics. This matrix is real (AMG).
SKJ	Integration matrix. Computes forces on the k-set degrees of freedom due to pressures at the aerodynamic control points. This matrix is for steady flows and is therefore real (AMG).
SKJF	Same as SKJ for unsteady aerodynamics. This matrix is for unsteady flows and is therefore complex (AMG).

Static Aeroelastic Solution

FFAJ	Vector of aerodynamic pressures on the aerodynamic control points for the trimmed air vehicle (AESTATRS subDMAP).
LSALL/USALL	These two matrices are upper and lower factors from the decomposition of $[KSAA] = [KAA + \bar{q}QAA]$ after it has been reduced to the l-set. They are used repeatedly in the computation of results for static aeroelasticity (AESTATRS subDMAP).
PAK	Vector of aerodynamic forces on the aerodynamic grid points for the trimmed air vehicle (AESTATRS subDMAP).

STBDER	Stability derivative table (SDP).
UX	Trim variable vector. Contains the values of the aerodynamic trim variables for the trim condition specified on the TRIM Bulk Data entry (ASG).

Generalized Aerodynamic Matrices

The following matrices are required in the modal aeroelastic solutions. The QHJ matrices are only required for gust analysis. All the matrices are complex.

QHJ	Generalized aerodynamics matrix with as many rows as there are aerodynamic control points and as many columns as there are retained modes (FLUTTER and MFREQRS subDMAPs).
QHJL	A "list" of QHJ matrices for all the user-requested Mach numbers and reduced frequencies. The total number of columns in the matrix is therefore the number of retained modes times the number of (m,k) pairs (FLUTTER and MFREQRS subDMAPs).
QHH	Generalized aerodynamics matrix with as many rows and columns as there are retained modes (FLUTTER and MFREQRS subDMAPs).
QHHL	A "list" of QHH matrices for all the user-requested Mach numbers and reduced frequencies. The total number of columns in the matrix is therefore the number of retained modes times the number of (m,k) pairs (FLUTTER and MFREQRS subDMAPs).

Flutter Solution

FLAMA	Table of flutter eigenvalues (FA2).
FPHH	Matrix of flutter eigenvectors (FA2).
OVG	Output flutter curve (V-G and V-F) requests (FA2).

Dynamic Aeroelasticity Solution

PHF	External loads in generalized coordinates. For dynamic aeroelastic analysis, this matrix contains any loads other than the ones due to aerodynamic gusts. There are as many rows as there are retained modes and as many columns as there are frequencies in the analysis (FRLG).
PHF1	Dynamic aeroelastic loads in generalized coordinates. This matrix is the summation of PHF and any aerodynamic gust loads. There are as many rows as there are retained modes and as many columns as there are frequencies in the analysis (GUST).
PKF	Matrix of aerodynamic forces at user-requested frequencies. The forces are provided at the user-requested (AEROF) aerodynamic degrees of freedom for the requested frequencies (ADR).

UHF	Matrix of generalized displacement results from the frequency response analysis. There are as many rows as there are retained modes and as many columns as there are frequencies in the analysis (FRRD2).
UHVT	Matrix of generalized displacement results in the time domain. This is an Inverse Fourier Transform of the UHF matrix and is computed when the user has supplied input, and requires output, in the time domain. There are as many rows as there are retained modes and as many columns as there are time steps in the user request time for displacement, velocity, and acceleration vectors (IFT).

Aeroelastic Design Sensitivity

DELFL	A table containing the flutter sensitivity data that is transferred to the DSCM matrix (DSFLTN).
DELS	A table containing stability derivative sensitivity data that is transferred to the DSCM matrix (DSARSN).
DELX	A table containing trim variable sensitivity data that is transferred to the DSCM matrix (DSARSN).
VTQU	A table containing scalars required in performing the flutter sensitivity calculation (DSFLTE).

7 Static Aeroelastic Analysis Problems

Overview

Static aeroelastic problems consider the application of steady-state aerodynamic forces to a flexible vehicle, which deflects under the applied loads resulting in perturbed aerodynamic forces. The solution of these problems assumes that the system comes to a state of static (or quasi-static) equilibrium. The aerodynamic load redistribution and consequent internal structural load and stress redistributions can be used for design purposes by structural analysts. The possibility of a static aeroelastic instability, that is, divergence, is also of concern to them. Static aeroelastic effects are of concern to other analysts as well. For example, aerodynamicists are concerned with the effects on induced drag, and control systems analysts are concerned with the effects on control effectiveness and static stability. The needs of these analysts from several related disciplines have been considered in the static aeroelastic capability of MSC Nastran.

Eight quasi-static examples are included in this chapter. These examples produce the symmetric and antisymmetric static stability derivatives as well as loads and stresses due to a variety of potential design conditions:

Examples		Description
HA144A	FSW Airplane in Level Flight	A half span symmetric model of an idealized forward swept wing (hereafter referred to as FSW) configuration
HA144B	Jet Transport Wing in Roll	It produces static aeroelastic results for the BAH wing [the jet transport wing analyzed throughout Bisplinghoff, Asheley, and Halfman (1955) [Reference 8]].
HA144C	A 15-Degree Sweptback Wing in a Wind Tunnel	considers a 15-deg swept untapered wing when mounted on a wind-tunnel wall at a prescribed angle of attack.
HA144D	FSW Airplane in Antisymmetric Maneuvers	It is the antisymmetric model of an idealized forward swept wing (hereafter referred to as FSW) configuration
HA144E	FSW Airplane in Unsymmetric Quasi-Steady Maneuvers	It is a full-span model of the FSW configuration
HA144F	FSW Airplane with Bodies	It adds a fuselage and two underwing stores to the HA144E example.
HA144GB	Unit Solutions for Loadings of the FSW Airplane	They use the FSW configuration to provide unit solutions for the loadings for the initial incidence and each of the trim variables.
HA144IR HA144IF	A 15-Degree Sweptback Wing with free pitch and plunge.	Separate runs create rigid aerodynamics and flexible corrections.

FSW Airplane in Level Flight

The first example is the FSW airplane considered by Rodden and Love (1985) [Reference 51] in trimmed level flight. The model is extremely idealized as shown in Figure 7-1. The wing has an aspect ratio of 4.0, no taper, twist, or camber, but an incidence of 0.1 deg relative to the fuselage, and a forward sweep angle of 30 deg. The canard has an aspect ratio of 1.0, no taper, twist, camber, incidence, or sweep, and is hinged about its quarter-chord. The chords of both the wing and canard are 10.0 ft, the reference chord is chosen as $\bar{c} = 10$ ft, and the reference area is $S = 200 \text{ sq ft}$ for the half-span model. Both subsonic ($m = 0.9$) and supersonic ($m = 1.3$) speeds are considered.

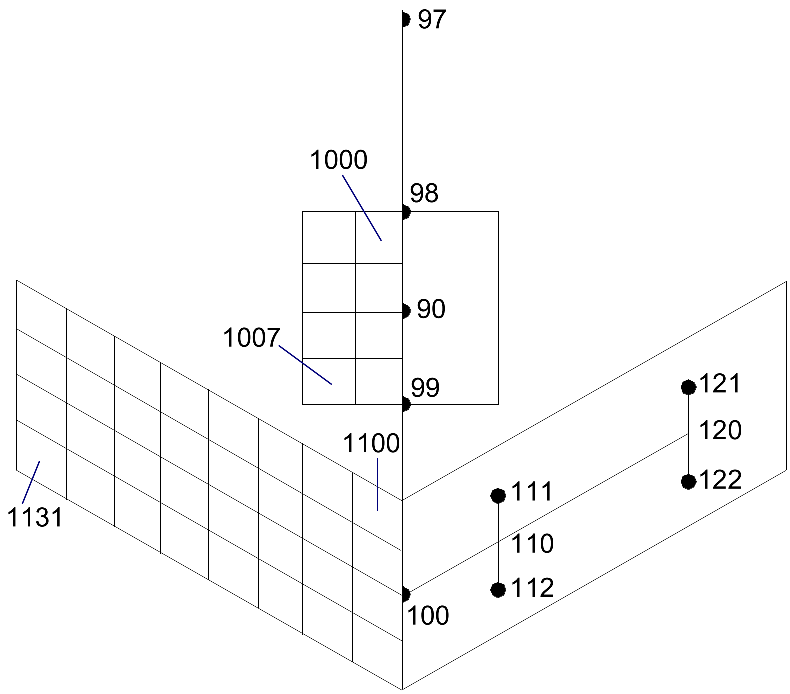


Figure 7-1 Idealization of FSW Configuration

The half-span model of the wing is divided into 32 equal aerodynamic boxes, as shown on the left wing in Figure 7-1, for both the Doublet-Lattice and ZONA51 methods of aerodynamic analysis, and the canard is divided into eight equal boxes, as also shown in Figure 7-1.

Aerodynamic forces on the fuselage are neglected. (Note that the right-hand side is modeled; the aerodynamic boxes are shown on the left side for convenience.) The right wing and fuselage in Figure 7-1 show the structural idealization.

Four weights are located at the one-quarter and three-quarter span and chord positions of the wing, and are assumed to be connected to the 50% chord elastic axis by rigid streamwise bars. The weights are 600 lb forward and 400 lb aft, giving a wing centroid at 45% of the wing chord. The wing is assumed to be uniform with equal bending (EL_y) and torsion (GJ) stiffnesses of 25×10^7 lb-ft^2 and is connected to the fuselage at its root. The right-side fuselage is assumed to have the same bending stiffness as the wing and is shown with four equal and equidistant weights (1500 lb each per side). The fuselage length is 30.0 ft. The total weight per side is 8000 lb, the center of gravity is 12.82 ft forward of the intersection of the fuselage and wing elastic axis, and the centroidal moment of inertia in pitch per side is $I_y = 892,900 \text{ lb-ft}^2$. For the subsonic case, the airplane is assumed to be flying at a Mach number $m = 0.9$ at sea level ($\bar{q} = 1200 \text{ psf}$). The low speed characteristics (but at $m = 0.9$) are obtained by assuming a low value of dynamic pressure, $\bar{q} = 40 \text{ psf}$, to illustrate the behavior of the quasi-rigid vehicle. In the supersonic case, the airplane is assumed to be flying at $m = 1.3$ at 20,000 ft ($\bar{q} = 1151 \text{ psf}$).

Bulk Data Input

The input data for this example is shown in Listing 7-1.

Structural Model

The input of structural data is considered first. The fuselage model is illustrated in Figure 7-1. The fuselage length from GRID 97 to GRID 100 is 30.0 ft. BAR elements are used between grid points, and a CONM2 weight of 1500 lb is at each fuselage grid point except GRID 90. The wing input is also illustrated in Figure 7-1.

Grid points 111, 112, 121, and 122 are connected to the elastic axis by rigid bars. The wing stiffnesses were assumed to be equal in bending and torsion, $EL_y = GJ = 25.0+07$; thus, assuming $E = 1.44+09 \text{ psf}$ and $G = 5.40+08 \text{ psf}$, leads to $I_y = 0.173611 \text{ ft}^4$ and $J = 0.462963 \text{ ft}^4$, respectively.

Values of cross-sectional area, $A = 1.5 \text{ ft}^2$, and chordwise inertia, $I_z = 2.0 \text{ ft}^4$, are chosen arbitrarily. A nominal symmetrical rectangular cross section with a 6.0 ft chord and 1.0 ft depth is also assumed for the wing structural box for stress recovery purposes at the four corners. The wing forward CONM2 weights are 600 lb, and the aft weights are 400 lb. The half-fuselage material properties are assumed to be the same as in the wing with the same vertical cross-sectional moment of inertia, $I_y = 0.173611 \text{ ft}^4$.

The remaining fuselage cross-sectional area properties are selected arbitrarily for stiffness and stress recovery, specifically, $A = 2.0 \text{ ft}^2$, $I_z = 0.15 \text{ ft}^4$, $J = 0.5 \text{ ft}^4$, and the points selected for stress recovery are at $y, z = \pm 1.0, \pm 1.0$.

There are two rigid body motions in this model: vertical translation and rotation in pitch. A SUPORT Bulk Data entry defines a reference point for these rigid body modes on GRID 90, DOFs 3 and 5. Component 4 (roll) of wing grid points 110 and 120 is omitted from the calculation in order to illustrate this means of reducing the problem size and thus has no effect on the results. GRID 90 is constrained longitudinally, and all of the fuselage grid points are constrained for symmetry using SPC1 entries. PARAM entries select GRID 90 as the inertial property reference point and convert the input weights to masses in slugs.

PARAM,WTMASS,1/G provides the conversion of weight to mass; PARAM,AUNITS,1/G allows for the input of the accelerations using load factors (Gs).] CORD2R 100 provides the NACA reference axes for the stability derivatives. The trim angle of attack is the angle of attack of the structural axis at the SUPORT point.

Aerodynamic Model

The Doublet-Lattice and ZONA51 methods for surfaces are specified on the CAERO1 entries. CAERO1 1000 specifies the canard with a 2×4 division into boxes. CAERO1 1100 specifies the wing with an 8×4 division into boxes. The PAERO1 entry is required even though the fuselage modeling is being neglected. Additional aerodynamic data are included in DMI entries to account for the differences between test and theory [the correction factors W_{kk} of (2-21)], experimental pressure data at some reference condition, for example, zero angle of attack, [the additive coefficients f^e also of (2-21)], and any initial downwash distribution arising, for example, from incidence, camber or twist [the additional downwash w_j^g of (2-2)].

In this example, $W_{kk} = WKK = 1.0$ and $f^e = FA2J = 0.0$ for all of the wing and canard aerodynamic boxes, and $w_j^g = W2GJ = 0.1 \quad \text{deg} = 0.001745 \text{ rad}$ for the wing boxes and $W2GJ = 0.0$ for the canard boxes.

The SPLINE2 1501 and SET1 1000 entries specify a linear spline on the canard to interconnect the structural and aerodynamic grids. The Cartesian coordinate system CORD2R 1 is for the spline on the canard through the one-quarter chord hinge line. The simplicity of the canard splining makes it uncharacteristic of what can be expected in practice, but it also provides an illustrative example of the use of the smoothing factors DTHX and DTHY. It is seen that DTHX has been set to 1.0, implying that the canard is restrained in roll about the centerline by a rotational spring. If DTHX were set to 0.0, the spline would be overdetermined since the two grid points that lie on the same line perpendicular to the spline axis each have a value for the bending slope when only one is allowed.

On the other hand, if DTHX were set to -1.0, the splining would become singular because displacements at two points are not sufficient to define a plane, that is, rotation of the canard about the centerline would not be precluded. Setting DTHY to -1.0 ensures that only the transverse displacements of the two grid points are used in determining the displacement and rotation of the spline.

The SPLINE2 1601 and SET1 1100 entries specify a linear spline on the wing. SET1 1100 includes GRIDs 99 and 100 for a good spline fit to the wing in the root region. CORD2R 2 is the Cartesian coordinate system through the wing elastic axis.

CORD2R 100 is for the rigid body motions of the aerodynamic reference point; specifically the pitch and moment axis is at the canard midchord at GRID 90. This coordinate system is the standard NACA body axis system with the x-axis forward and the z-axis downward. The stability derivatives are output using this coordinate system.

Static Aeroelastic Input

The foregoing input is typical for any aeroelastic analysis. The entries in the Bulk Data specifically for static aeroelastic analysis begin with the AESTAT entries, which specify the trim parameters. The parameters are angle of attack, $\alpha = \text{ANGLEA}$; pitch rate, $q\bar{c}/2V = \text{PITCH}$; normal load factor $\ddot{z}/g = URDD3$; and pitch acceleration, $\ddot{\theta}/g = URDD5$. Next, the trim surface is defined by an AESURF entry as the elevator (canard) ELEV using coordinate system CORD2R 1 for its hinge line and defining the aerodynamic boxes using AELIST 1000, which specifies aerodynamic box numbers 1000 through 1007. The reference geometry is specified on the AEROS entry. This entry specifies the aerodynamic coordinate system CORD2R 1, the aerodynamic reference coordinate system for rigid body motions CORD2R 100, a reference chord of $\text{REFC} = \bar{c} = 10.0\text{ ft}$, a reference span of $\text{REFB} = b = 40.0\text{ ft}$ (the full span), a reference area of $\text{REFS} = S = 200.0\text{ sq ft}$ (half-model), and symmetric aerodynamic loading (SYMXZ = 1). The first two TRIM entries specify the flight condition at Mach number, $m = 0.9$ and level flight with no pitch rate, $q\bar{c}/2V = \text{PITCH} = 0.0$, a one-g load factor, $\ddot{z}/g = \text{URDD3} = -1.0$, and no pitching acceleration, $\dot{q}/g = \ddot{\theta}/g = \text{URDD5} = 0.0$. The first entry, TRIM 1, specifies the low speed condition with dynamic pressure $\bar{q} = Q = 40\text{ psf}$, and the second entry, TRIM 2, specifies $\bar{q} = Q = 1200\text{ psf}$, both at $m = 0.9$ at sea level. The third entry, TRIM 3, specifies supersonic level flight at $m = 1.3$ at 20,000 ft with $Q = 1151\text{ psf}$.

Monitor Point Input

User input is provided for the production of a number of monitor point results as discussed in Monitor Points of Chapter 3). Two MONPNT1's create load summations on the aero and structural model. The structural MONPNT1 has the name WNGSTRC and points to an AECOMP of the same name which in turns invokes a SET1 entry that lists the six grids shown on the wing of Figure 7-1. The aerodynamic MONPNT1 has the name WNGAERO and points to an AECOMP with the same name which in turn invokes an AELIST entry that specifies all the aerodynamic boxes on the wing, also as shown in Figure 7-1. A MONSUM entry adds the results of the structural and aerodynamic MONPNT1 with a negative sign to determine how well these two sets of loads equate.

Four MONPNT2 entries pinpoint bending and axial stresses at End A of the two CBAR elements that represent the wing elastic axis.

Similar to the MONPNT1 input, two MONDSP1 entries request representative displacements on the structural and aerodynamic model. The structural MONDSP1 has the name RWTSD and invokes an AECOMP of the same name which in turn calls out a SET1 entry that has the three grids at the structural tip of the model. The aerodynamic MONDSP1 has the name RWTAD and invokes an AECOMP of the same name which, in turn, calls out a AELIST entry that selects the two outer strips of aerodynamic boxes (boxes 1124 through 1131 in Figure 7-1).

Finally, two MONCNCM entries request strip results for the wing and canard.

Case Control Commands

The Case Control Section begins with three title commands. ECHO = BOTH echoes the input data in both unsorted/annotated and in sorted/unannotated formats. SPC = 1 provides the set of symmetric constraints. DISP, STRESS, and FORCE = ALL print all of the displacements, stresses, and forces, respectively. AEROF, APRES = ALL call for all of the aerodynamic forces and pressures to be printed in all subcases: SUBCASE 1 (TRIM = 1) is the low $\bar{q}$ case of level flight at Mach number $m = 0.9$; SUBCASE 2 (TRIM = 2) is the high $\bar{q}$ case at $m = 0.9$; SUBCASE 3 is the supersonic flight case at $m = 1.3$. The OUTPUT(PLOT) request permits graphs to be obtained from auxiliary plotting equipment. In this case, the planform is plotted.

In the Executive Control statement, ID MSC, HA144A indicates the identification of this problem. SOL 144 calls for the Static Aeroelastic Response DMAP sequence.

CSV Request

Two assign statements at the top of Listing 7-1 invoke files that are to be used for the storage of stability derivatives and monitor point results as described in Rigid/Flexible Aerodynamics. There are four related parameters in the bulk data section:

- PARAM LDSUM 2 $ Requests limited structural monitor point output
- PARAM SDCSV 63 $ Requests all available stability derivative output
- PARAM XYUNIT 52 $ Output unit for csv file containing monitor point results
- PARAM SDUNIT 51 $ Output unit for csv file containing stability derivative results

Listing 7-1 Input Files for FSW Airplane in Level Flight

```
ASSIGN USERFILE='HA144CSVT.CSV' STATUS=UNKNOWN FORM=FORMATTED UNIT=52
    ASSIGN USERFILE='HA144CSVS.CSV' STATUS=UNKNOWN FORM=FORMATTED UNIT=51
    ID MSC, HA144A    $
    $$$     USERS GUIDE FOR AEROEELASTIC ANALYSIS EXAMPLE HA144A    $$$$$$$$
    $                                                                      $
    $       MODEL DESCRIPTION        30 DEG FWD SWEPT WING W/CANARD        $
    $                                BEAM MODEL WITH DUMBBELL MASSES       $
    $                                                                      $
    $       SOLUTION                 SYMMETRIC IN-FLIGHT STATIC STABILITY  $
    $                                ANALYSIS USING DOUBLET-LATTICE        $
    $                                METHOD AERODYNAMICS AT MACH NO. 0.9   $
    $                                AND ZONA51 AERO AT MACH NO. 1.3       $
    $                                                                      $
    $       OUTPUT                   LISTS OF RESTRAINED AND               $
    $                                UNRESTRAINED SYMMETRIC STATIC         $
    $                                STABILITY DERIVATIVES PLUS THE        $
    $                                AERODYNAMIC FORCES AND PRESSURES      $
    $                                PLUS STRESSES AND DEFLECTIONS FOR     $
    $                                1G LEVEL FLIGHT.                      $
    $                                                                      $
    $$$$$$$$                                                        $$$$$$$$

$
    $ THIS TEST CASE WILL CAUSE THE OUTPUT OF TWO CSV FILES. THE FIRST
    $ CONTAINS THE FOLLOWING DATA FOR EACH AEROELASTIC SUBCASE:
    $    1. SUBCASE ID
    $    2. MACH NUMBER
    $    3. DYNAMIC PRESSURE
    $    4. TRIM VALUES
    $    5. MASS AND CENTER OF GRAVITY
    $    6. NET MONPNT1, MONPNT2, AND MONDSP1 RESULTS.
    $    7. MONPNT1 RIGID AIR, ELASTIC RESTRAINED, INERTIAL,
    $       RIGID APPLIED, AND ELASTIC APPLIED RESULTS
    $  THE SECOND CONTAINS ITEMS 1-3 AND 5 FROM ABOVE PLUS ALL THE
    $  STABILITY DERIVATIVES
    $
    TIME 5 $ CPU TIME IN MINUTES
    SOL 144 $ STATIC AERO
    CEND
```

Listing 7-1 Input Files for FSW Airplane in Level Flight (Continued)

```
0                          C A S E   C O N T R O L   E C H O
            COMMAND
            COUNT
             1     TITLE = EXAMPLE HA144A: 30 DEG FWD SWEPT WING WITH CANARD HA14 HA144A
             2     SUBTI = SYMMETRIC FLIGHT CONDITIONS, DOUBLET-LATTICE AERO
             3     LABEL = HALF-SPAN MODEL, STATIC SYMMETRIC LOADING
             4       ECHO    = BOTH
             5       SPC     = 1   $ SYMMETRIC CONSTRAINTS
             6       DISP    = ALL $ PRINT ALL DISPLACEMENTS
             7       STRESS  = ALL $ PRINT ALL STRESSES
             8       FORCE   = ALL $ PRINT ALL FORCES
             9       AEROF   = ALL $ PRINT ALL AERODYNAMIC FORCES
             10      APRES   = ALL $ PRINT ALL AERODYNAMIC PRESSURES
             11      GPFO    = ALL $ PRINT ALL GRID POINT FORCES
             12      SUBCASE 1
             13       TRIM = 1     $ 1 G LEVEL FLIGHT (LOW SPEED)
             14      SUBCASE 2
             15       TRIM = 2     $ 1 G LEVEL FLIGHT (HIGH SUBSONIC SPEED)
             16      SUBCASE 3
             17       TRIM = 3     $ 1 G LEVEL FLIGHT (LOW SUPERSONIC SPEED)
             18       BEGIN BULK

                           I N P U T   B U L K   D A T A   E C H O
       ENTRY
       COUNT      .  1  ..  2  ..  3  ..  4  ..  5  ..  6  ..  7  ..  8  ..  9  ..  10  .
         57-        $*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
         58-        $                                                                        $
         59-        $        THE ANNOTATIONS IN THIS INPUT SECTION ARE INTENDED TO           $
         60-        $        EXPLAIN THE DATA ON THE ENTRY IMAGES FOR THIS SPECIFIC          $
         61-        $        EXAMPLE WITHOUT REFERENCE TO THE VARIOUS GUIDES WHERE          $
         62-        $        MORE GENERAL DESCRIPTIONS WILL BE FOUND.                        $
         63-        $                                                                        $
         64-        $*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
         65-        $                                                                        $
         66-        $                      * * * STRUCTURAL DATA * * *                       $
         67-        $                                                                        $
         68-        $                           (LB-FT-SEC SYSTEM)                           $
         69-        $                                                                        $
         70-        $                         * * GRID GEOMETRY * *                          $
         71-        $                                                                        $
         72-        $        GRID  90 - 100 (T3) FUSELAGE POINTS                             $
         73-        $        GRID 110 - 122 (T3) WING POINTS                                 $
         74-        $                                                                        $
         75-        $                           * FUSELAGE GRID *                            $
         76-        $                                                                        $
         77-        $        THE GRID ENTRY DEFINES THE LOCATION OF A STRUCTURAL GRID        $
         78-        $        POINT.  LISTED ARE ITS COORDINATE SYSTEM ID, ITS LOCATION,      $
         79-        $        THE ID OF THE COORDINATE SYSTEM IN WHICH ITS DISPLACEMENTS      $
         80-        $        ARE DEFINED, ITS PERMANENT SINGLE-POINT CONSTRAINTS AND         $
         81-        $        ITS ASSOCIATED SUPERELEMENT ID.                                 $
         82-        $                                                                        $
         83-        $       ID      CP      X1      X2      X3      CD      PS      SEID
         84-        GRID    90              15.     0.      0.
         85-        GRID    97              0.      0.      0.
         86-        GRID    98              10.     0.      0.
         87-        GRID    99              20.     0.      0.
         88-        GRID    100             30.     0.      0.
         89-        $                                                                        $
         90-        $                            * WING GRID *                               $
         91-        $                                                                        $
         92-        $       ID      CP      X1      X2      X3      CD      PS      SEID
         93-        GRID    111             24.61325 +5.    0.
```

Listing 7-1 Input Files for FSW Airplane in Level Flight (Continued)

```
GRID    110             27.11325 +5.    0.
GRID    112             29.61325 +5.    0.
GRID    121             18.83975+15.    0.
GRID    120             21.33975+15.    0.
GRID    122             23.83975+15.    0.
 $                                                                       $
 $                * * STRUCTURAL STIFFNESS PROPERTIES * *                $
 $                                                                       $
 $                        * FUSELAGE STRUCTURE *                         $
 $                                                                       $
 $        THE CBAR ENTRY DEFINES A SIMPLE BEAM ELEMENT.  LISTED ARE      $
 $        ITS PROPERTY ENTRY ID, THE TWO GRID POINTS JOINED BY THE       $
 $        BEAM AND COMPONENTS OF A VECTOR FROM THE FIRST POINT.          $
 $        THIS VECTOR DEFINES THE DIRECTION OF THE STRUCTURAL DE-        $
 $        FLECTION OF THE POINT AND ITS POSITIVE SENSE.                  $
 $                                                                       $
 $       EID     PID     GA      GB      X1,GO   X2      X3
 CBAR    101     100     97      98      0.      0.      1.
 CBAR    102     100     98      90      0.      0.      1.
 CBAR    100     100     90      99      0.      0.      1.
 CBAR    103     100     99      100     0.      0.      1.
 $                                                                       $
 $        THE PBAR ENTRY DEFINES GEOMETRIC PROPERTIES OF THE BEAM.       $
 $        LISTED ARE ITS ASSOCIATED MATERIAL ENTRY ID, ITS CROSS SEC-    $
 $        TIONAL AREA, AREA MOMENTS OF INERTIA, TORSIONAL MOMENT         $
 $        OF INERTIA AND NON-STRUCTURAL MASS PER UNIT AREA.  THE         $
 $        OPTIONAL CONTINUATION ENTRY CONTAINS STRESS RECOVERY           $
 $        COEFFICIENTS, I.E., Y,Z COORDINATES WHERE STRESSES ARE         $
 $        TO BE COMPUTED.  K1 AND K2 ARE AREA FACTORS FOR SHEAR          $
 $        STIFFNESS (DEFAULT IS BLANK; THEN SHEAR STIFFNESS IS           $
 $        INFINITE, I.E., SHEAR FLEXIBILITY IS ZERO.  I12 IS THE         $
 $        AREA PRODUCT OF INERTIA.                                       $
 $                                                                       $
 $       PID     MID     A       I1      I2      J       NSM
 PBAR    100     1       2.0     .173611 0.15    0.5                    +PB1
 $       C1      C2      D1      D2      E1      E2      F1      F2
 +PB1    1.0     1.0     1.0     -1.0    -1.0    1.0     -1.0    -1.0   +PB2
 $       K1      K2      I12
 +PB2                    0.0
 $                                                                       $
 $                           * WING STRUCTURE *                          $
 $                                                                       $
 $       EID     PID     GA      GB      X1,GO   X2      X3
 CBAR    110     101     100     110     0.      0.      1.
 CBAR    120     101     110     120     0.      0.      1.
 $                                                                       $
 $        THE RBAR ENTRY DEFINES A RIGID BAR.  LISTED ARE THE GRID       $
 $        POINTS AT EACH END AND THE DEPENDENT AND INDEPENDENT DOFS      $
 $        AT EACH END.  THE NUMBER OF INDEPENDENT DOFS AT THE TWO        $
 $        ENDS MUST EQUAL SIX.  BY DEFAULT THOSE NOT DECLARED INDE-      $
 $        PENDENT ARE MADE DEPENDENT.                                    $
 $                                                                       $
 $       EID     GA      GB      CNA     CNB     CMA     CMB
 RBAR    111     110     111     123456
 RBAR    112     110     112     123456
 RBAR    121     120     121     123456
 RBAR    122     120     122     123456
 $                                                                       $
 $       PID     MID     A       I1      I2      J       NSM
 PBAR    101     1       1.5     0.173611+2.0    0.462963               +PB3
 $       C1      C2      D1      D2      E1      E2      F1      F2
 +PB3    0.5     3.0     0.5     -3.0    -0.5    3.0     -0.5    -3.0   +PB4
```

Listing 7-1 Input Files for FSW Airplane in Level Flight (Continued)

```
$       K1      K2      I12
+PB4                    0.0
$                                                                      $
$        THE MAT1 ENTRY DEFINES THE MATERIAL PROPERTIES.  LISTED       $
$        ARE ITS ID, ITS ELASTIC MODULUS, SHEAR MODULUS, POISSONS      $
$        RATIO, MASS DENSITY, TEMPERATURE EXPANSION COEFFICIENT,       $
$        REFERENCE TEMPERATURE AND A STRUCTURAL DAMPING COEFFICIENT.   $
$                                                                      $
$       MID     E       G       NU      RHO     A       TREF    GE
MAT1    1       1.44+9  5.40+8
$                                                                      $
$                 * * MASS AND INERTIA PROPERTIES * *                  $
$                                                                      $
$                          * FUSELAGE MASSES *                         $
$                                                                      $
$        THE CONM2 ENTRY DEFINES A CONCENTRATED MASS.  LISTED ARE      $
$        ITS ID, GRID LOCATION, COORDINATE SYSTEM TO LOCATE THE        $
$        CENTER OF GRAVITY, THE MASS VALUE AND THE LOCATION OF         $
$        THE CENTER OF GRAVITY RELATIVE TO THE GRID LOCATION.          $
$                                                                      $
$       EID     G       CID     M       X1      X2      X3
CONM2   97      97      0       1500.0
CONM2   98      98      0       1500.0
CONM2   99      99      0       1500.0
CONM2   100     100     0       1500.0
$                                                                      $
$                            * WING MASSES *                           $
$                                                                      $
CONM2   311     111     0       600.0
CONM2   312     112     0       400.0
CONM2   321     121     0       600.0
CONM2   322     122     0       400.0
$                                                                      $
$                   * * STRUCTURAL PARAMETERS * *                      $
$                                                                      $
$        THE PARAM,GRDPNT,XX ENTRY CAUSES THE GRID POINT WEIGHT        $
$        GENERATOR TO BE EXECUTED USING GRID POINT XX AS THE REF-      $
$        ERENCE POINT.  THEN THE INERTIA MATRIX, THE TRANSFER MATRIX   $
$        FROM BASIC TO PRINCIPAL AXES AND OTHER PERTINENT INERTIA      $
$        DATA ARE PRINTED.                                             $
$                                                                      $
PARAM   GRDPNT  90
$                                                                      $
$        THE PARAM,WTMASS,GINV CAUSES ALL THE STRUCTURAL MASSES AND    $
$        MASS DENSITIES TO BE MULTIPLIED BY GINV (I.E., BY ONE OVER    $
$        THE ACCELERATION OF GRAVITY).  THE DYNAMIC PRESSURE SUPPLIED  $
$        FOR AERODYNAMIC FORCE CALCULATIONS WILL NOT BE MULTIPLIED     $
$        BY GINV.                                                      $
$                                                                      $
PARAM   WTMASS  .031081
$
$        THE PARAM,AUNITS,GINV PERMITS THE ACCELERATIONS ON THE TRIM
$        ENTRY TO BE SPECIFIED IN UNITS OF LOAD FACTOR (I.E., IN G'S)
$
PARAM   AUNITS  .031081
PARAM   LDSUM   2  $
PARAM   SDCSV   63  $
PARAM   XYUNIT  52 $
PARAM   SDUNIT  51 $
$                                                                      $
$                  * * STRUCTURAL CONSTRAINTS * *                      $
$                                                                      $
```

Listing 7-1 Input Files for FSW Airplane in Level Flight (Continued)

```
$        THE SPC1 ENTRY CONSTRAINS THE LISTED GRID POINTS IN THE         $
$        SPECIFIED DOF COMPONENTS.                                       $
$                                                                        $
$       SID     C       G1      G2      G3      G4
SPC1    1       1246    90
SPC1    1       246     97      98      99      100
$                                                                        $
$        THE SUPORT ENTRY IDENTIFIES A GRID POINT OR A SCALAR POINT      $
$        AND SPECIFIES THE DOF COMPONENTS IN WHICH THE USER DESIRES      $
$        REACTIONS TO BE APPLIED TO PREVENT RIGID BODY MOTION.  IT       $
$        THUS INVOKES THE SOLUTION OF THE BALANCE EQUATIONS TO DETER-    $
$        MINE THE REACTIONS.  IN THE STATIC AEROELASTIC SOLUTION         $
$        THE DOF COMPONENTS MUST BE CONSISTENT WITH THE UNDEFINED        $
$        VARIABLES ON THE TRIM ENTRIES.                                  $
$                                                                        $
$       ID      C
SUPORT  90      35
$                                                                        $
$                     * * * AERODYNAMIC DATA * * *                       $
$                                                                        $
$                          (LB-FT-SEC SYSTEM)                            $
$                                                                        $
$                       * * ELEMENT GEOMETRY * *                         $
$                                                                        $
$        THE AEROS ENTRY IS UNIQUE TO THE STATIC AEROELASTICITY          $
$        SOLUTION, SOL21.  ACSID IDENTIFIES THE AERO COORDINATE          $
$        SYSTEM, RCSID IDENTIFIES THE REFERENCE COORDINATE SYS-          $
$        TEM FOR RIGID BODY MOTION.  REFC IS THE REFERENCE CHORD.        $
$        REFB IS THE REFERENCE SPAN.  REFS IS THE REFERENCE WING         $
$        AREA.  SYMXZ AND SYMXY ARE SYMMETRY KEYS.                       $
$                                                                        $
$      ACSID    RCSID   REFC    REFB    REFS    SYMXZ   SYMXY
AEROS   1        100    10.0    40.0    200.0    1
$                                                                        $
$        THIS CORD2R ENTRY DEFINES THE AERO COORDINATE SYSTEM            $
$        FLAGGED BY THE AEROS ENTRY.  THE ORIGIN IS AT THE CANARD        $
$        QUARTER CHORD.  LISTED ARE THE ORIGIN, A POINT ALONG THE        $
$        Z AXIS AND A POINT IN THE X-Z PLANE, ALL IN THE RID             $
$        COORDINATE SYSTEM.                                              $
$                                                                        $
$       CID     RID     A1      A2      A3      B1      B2      B3
CORD2R  1       0       12.5    0.      0.      12.5    0.      10.     +CRD1
$       C1      C2      C3
+CRD1   20.     0.      0.
$                                                                        $
$        THIS CORD2R ENTRY DEFINES THE NACA COORDINATE SYSTEM TO         $
$        WHICH ALL THE STABILITY DERIVATIVES AND TRIM CONDITIONS         $
$        WILL BE REFERENCED.                                             $
$                                                                        $
$       CID     RID     A1      A2      A3      B1      B2      B3
CORD2R  100     0       15.0    0.0     0.0     15.0    0.0     -10.0   +CRD100
$       C1      C2      C3
+CRD100 0.0     0.0     0.0
$                                                                        $
$                * * SPLINE FIT ON THE LIFTING SURFACES * *              $
$                                                                        $
$                     * BEAM SPLINE FIT ON THE WING *                    $
$                                                                        $
$        THE SPLINE2 ENTRY SPECIFIES A BEAM SPLINE FOR INTERPOLAT-       $
$        ION OVER THE REGION OF THE CAERO ENTRY (ID1 AND ID2 ARE         $
$        THE FIRST AND LAST BOXES IN THIS REGION).  SETG REFERS          $
$        TO A SET1 ENTRY WHERE THE STRUCTURAL GRID POINTS ARE            $
```

Listing 7-1 Input Files for FSW Airplane in Level Flight (Continued)

```
$       DEFINED.  DZ AND DTOR ARE SMOOTHING CONSTANTS FOR LINEAR        $
$       ATTACHMENT AND TORSIONAL FLEXIBILITIES.  CID IDENTIFIES         $
$       THE CORD2R ENTRY THAT DEFINES THE SPLINE AXIS.  DTHX AND        $
$       DTHY ARE ROTATIONAL ATTACHMENT FLEXIBILITIES (-1. SPECIFIES     $
$       NO ATTACHMENT).                                                 $
$                                                                       $
$       EID     CAERO   ID1     ID2     SETG    DZ      DTOR    CID
SPLINE2 1601    1100    1100    1131    1100    0.      1.      2       +SPW
$       DTHX    DTHY
+SPW    -1.     -1.
$                                                               $
$       THE CAERO1 ENTRY IS USED FOR DOUBLET-LATTICE AERODYNAMICS.      $
$       LISTED ARE ITS PAERO ENTRY ID AND THE COORDINATE SYSTEM         $
$       FOR LOCATING THE INBOARD AND OUTBOARD LEADING EDGE POINTS       $
$       (1 AND 4).  NSPAN AND NCHORD, OR LSPAN AND LCHORD, ARE          $
$       USED TO PARTITION THE WING INTO AERODYNAMIC PANELS,             $
$       THE FORMER FOR UNIFORMLY SPACED PANELS AND THE LATTER           $
$       FOR NON-UNIFORMLY SPACED PANELS.  IGID IS THE ID OF ITS         $
$       ASSOCIATED INTERFERENCE GROUP.  THE CONTINUATION ENTRY          $
$       DEFINES POINTS 1 AND 4, THE ROOT CHORD AND TIP CHORD.           $
$       THE BOXES FORMED BY THE GRID LINES WILL BE NUMBERED             $
$       BEGINNING WITH EID SO CHOOSE A NUMBER THAT IS UNIQUE,           $
$       AND IS GREATER THAN ALL STRUCTURAL GRID, SCALAR AND             $
$       EXTRA POINT IDS.                                                $
$                                                                       $
$       EID     PID     CP      NSPAN   NCHORD  LSPAN   LCHORD  IGID
CAERO1  1100    1000            8       4                       1       +CAW
$      ( FWD LEFT POINT  )      CHORD ( FWD RIGHT POINT   )     CHORD
$       X1      Y1      Z1      X12     X4      Y4      Z4      X14
+CAW    25.     0.      0.      10.     13.45299+20.    0.      10.
$                                                                       $
$       THE PAERO1 ENTRY IS REQUIRED EVEN THOUGH IT IS NON-FUNCTIONAL   $
$       (BECAUSE THERE ARE NO ASSOCIATED BODIES IN THIS EXAMPLE).       $
$                                                                       $
$       PID     B1      B2      B3      B4      B5      B6
PAERO1  1000
$                                                                       $
$       THE SET1 ENTRY DEFINES THE SETS OF STRUCTURAL GRID POINTS       $
$       TO BE USED BY THE BEAM SPLINE FOR INTERPOLATION.                $
$                                                                       $
$       SID     G1      G2      G3      G4
SET1    1100    99      100     111     112     121     122
$
$       THE CORD2R ENTRY DEFINES THE COORDINATE SYSTEM IN WHICH THE     $
$       BEAM SPLINE EXTENDS ALONG THE WING Y-AXIS.  IT LISTS THE        $
$       ORIGIN, A POINT ALONG THE Z-AXIS AND A POINT IN THE X-Z         $
$       PLANE.                                                          $
$                                                                       $
$       CID     CS      A1      A2      A3      B1      B2      B3
CORD2R  2       0       30.     0.      0.      30.     0.      10.     +CRD2
$       C1      C2      C3
+CRD2   38.66025+5.0    0.
$                                                                       $
$                 * CONTROL SURFACE DEFINITION *                        $
$                                                                       $
$       THE AESURF ENTRY DEFINES AN AERODYNAMIC CONTROL SURFACE.        $
$       LISTED ARE THE ALPHANUMERIC NAME OF THE SURFACE, THE ID         $
$       OF A COORDINATE SYSTEM THAT DEFINES THE HINGE LINE AND          $
$       THE ID OF AN AELIST ENTRY.                                      $
$                                                                       $
$       ID      LABEL   CID1    ALID1   CID2    ALID2
AESURF  505     ELEV    1       1000
```

Main Index

Listing 7-1 Input Files for FSW Airplane in Level Flight (Continued)

```
$                                                                        $
$        THE AELIST ENTRY LISTS AERODYNAMIC BOXES THAT LIE ON THE        $
$        CONTROL SURFACE.                                                $
$                                                                        $
$       SID     E1      E2      E3      ETC
AELIST  1000    1000    THRU    1007
$                                                                        $
$                 * BEAM SPLINE FIT ON THE CANARD *                      $
$                                                                        $
$       AGRID   PANEL (FIRST & LAST BOX)SGRID                   SPLCS
SPLINE2 1501    1000    1000    1007    1000    0.      1.      1       +SPC
+SPC    1.      -1.
$                                                                        $
$       PANEL    PID    CS      NSPAN   NCHORD                  IGP
CAERO1  1000    1000            2       4                       1       +CAC
$      (FWD LEFT POINT       ) CHORD  (FWD RIGHT POINT      )  CHORD
+CAC    10.     0.      0.      10.     10.     5.      0.      10.
$                                                                        $
$       SGRID    GRID POINTS
SET1    1000    98      99
$                                                                        $
$                                                                        $
$                    * * * AERODYNAMIC DATA * * *                        $
$                                                                        $
$                  * * USER SUPPLIED INPUT DATA * *                      $
$                                                                        $
$        THE DMI ENTRY ACCOMMODATES DIRECT INPUT OF USER SUPPLIED        $
$        MATRICES OF DATA.  LISTED ARE THE NAME OF THE MATRIX, THE       $
$        FORM OF MATRIX (IN THIS CASE DIAGONAL), THE TYPE OF DATA        $
$        (IN THIS CASE REAL SINGLE PRECISION), BEING INPUT AND THE       $
$        TYPE EXPECTED AT OUTPUT (IN THIS CASE TO BE DETERMINED          $
$        INTERNALLY).  M IS THE NUMBER OF ROWS AND N IS THE NUMBER       $
$        OF COLUMNS.  THE DATA IS EXPECTED BY COLUMNS.  THE CONTIN-      $
$        UATION ENTRY LISTS THE COLUMN NO., THE ROW NO. OF THE FIRST     $
$        NON-ZERO ELEMENT AND THE FOLLOWING ELEMENTS IN THAT COLUMN.     $
$                                                                        $
$              * PRESSURE MODIFIERS (WEIGHTING MATRIX) *                 $
$                                                                        $
$       NAME    "0"     FORM    TIN     TOUT            M       N
DMI     WKK     0       3       1       0               80      1
$       NAME    J       I1      A(I1,J) A(I1+1,J) . . .
DMI     WKK     1       1       1.0     THRU    80
$                                                                        $
$     * INITIAL DOWNWASHES (E.G., DUE TO INCIDENCE,TWIST OR CAMBER) *    $
$                                                                        $
DMI     W2GJ    0       2       1       0               40      1
DMI     W2GJ    1       9       .0017453THRU    40
$                                                                        $
$             * PRESSURES (E.G., AT ZERO ANGLE OF ATTACK) *              $
$                                                                        $
DMI     FA2J    0       2       1       0               40      1
DMI     FA2J    1       1       0.0     THRU    40
$                                                                        $
$                                                                        $
$                * * * SOLUTION SPECIFICATIONS * * *                     $
$                                                                        $
$                     * * AERODYNAMIC DOFS * *                           $
$                                                                        $
$        THE AESTAT ENTRY LISTS TRIM VARIABLES USED TO SPECIFY           $
$        RIGID BODY MOTIONS.  THESE AND THE CONTROL SURFACE              $
$        ROTATIONS MAKE UP THE VARIABLES IN THE EQUATIONS OF             $
$        MOTION.                                                         $
```

Listing 7-1 Input Files for FSW Airplane in Level Flight (Continued)

```
$                                                                       $
$       ID      LABEL
AESTAT  501     ANGLEA
AESTAT  502     PITCH
AESTAT  503     URDD3
AESTAT  504     URDD5
$                                                                       $
$                        * * TRIM CONDITIONS * *                        $
$                                                                       $
$        THE TRIM ENTRY SPECIFIES CONSTRAINTS FOR THE TRIM VARIABLES    $
$        LISTED ON THE AESTAT AND AESURF ENTRIES.  LISTED ARE ITS ID,   $
$        THE MACH NUMBER, DYNAMIC PRESSURE AND PAIRS OF TRIM VARI-      $
$        ABLES AND THEIR CONSTRAINED VALUES.  THOSE THAT ARE NOT        $
$        HELD FIXED MUST BE CONSTRAINED BY REACTION FORCES STIPU-       $
$        LATED ON THE SUPORT ENTRY.  SEE SECTION 3.5.3 OF THE THEO-     $
$        RETICAL MANUAL FOR MORE DETAILS.                               $
$                                                                       $
$        TRIM CONDITION 1: 1 G LEVEL FLIGHT AT LOW SPEED                $
$                                                                       $
$       ID      MACH    Q       LABEL1  UX1     LABEL2  UX2             +TRM
TRIM    1       0.9     40.0    PITCH   0.0     URDD3   -1.0            +TR1
$       LABEL3  UX3
+TR1    URDD5   0.0
$                                 * * *                                 $
$        TRIM CONDITION 2: 1 G LEVEL FLIGHT AT HIGH SUBSONIC SPEED      $
$                                                                       $
TRIM    2       0.9     1200.0  PITCH   0.0     URDD3   -1.0            +TR2
+TR2    URDD5   0.0
$                                 * * *                                 $
$        TRIM CONDITION 3: 1 G LEVEL FLIGHT AT LOW SUPERSONIC SPEED     $
$                                                                       $
TRIM    3       1.3     1151.0  PITCH   0.0     URDD3   -1.0            +TR3
+TR3    URDD5   0.0
$
AECOMP  WINGSTRCSET1    1
SET1    1       110     111     112     120     121     122
MONPNT1 WINGSTRCWING STRUCTURE
+       123456  WINGSTRC2
$
AECOMP  WINGAEROAELIST  2
AELIST  2       1100    THRU    1131
MONPNT1 WINGAEROWING AERO
+       35      WINGAERO2
$
MONSUM  WINGSUM    SUMMATION OF WING AERO AND STRUCTURAL LOADS
        123456  AMONPNT1WINGAERO  35     1.0
                SMONPNT1WINGSTRC  35    -1.0
$MONPNT2NAME    LABEL                                                   +
$+      TABLE   TYPE    NDDLITEM EID
MONPNT2 RWISX1A RIGHT WING INBOARD STRESS
+       STRESS  CBAR    SX1A    110
MONPNT2 RSOSX1A RIGHT WING OUTBOARD STRESS
+       STRESS  CBAR    SX1A    120
MONPNT2 RWIAS   RIGHT WING INBOARD AXIAL STRESS
+       STRESS  CBAR    AS      110
MONPNT2 RSOAS   RIGHT WING OUTBOARD AXIAL STRESS
+       STRESS  CBAR    AS      120
$
$ RIGHT WING TIP STRUCTURAL DISPLACEMENT
MONDSP1 RWTSD   RIGHT WING TIP STRUCTURAL DISPLACEMENT
+       123456  RWTSD           106.077 180.    0.              123
```

Listing 7-1 Input Files for FSW Airplane in Level Flight (Continued)

```
AECOMP  RWTSD   SET1    10004
SET1    10004   110     120     121     122
$
$
$ RIGHT WING TIP AERO DISPLACMENT
MONDSP1 RWTAD   RIGHT WING TIP AERO DISPLACMENT
+       35      RWTAD           71.43591240.    0.              123
AECOMP  RWTAD   AELIST  10003
AELIST  10003   1124    THRU    1131
$
$ STRIP RESULTS FOR THE ENTIRE AIRPLANE
MONCNCM CNCMWING   NORMAL FORCE AND PITCHING MOMENT COEFFICIENTS AT TRIM
                1100
MONCNCM CNCMCAN    NORMAL FORCE AND PITCHING MOMENT COEFFICIENTS AT TRIM
                1000
```

.f06 Output

Portions of the output results from the .f06 filethat are unique to aeroelastic analysis are shown in Listing 7-2 and summarized here.

Stability Derivatives

The typical definition of the stability derivatives in the restrained longitudinal case may be illustrated by the lift coefficient [see, for example, Rodden and Love (1985) [Reference 51], and note that $C_z = -C_L$]:

$$C_z = C_{z_o} + C_{z_\alpha}\alpha + C_{z_{\delta_e}}\delta_e + C_{z_q}\frac{q\bar{c}}{2V} + C_{z_{\dot{\alpha}}}\frac{\dot{\alpha}\bar{c}}{2V} + C_{z_{\ddot{z}}}\frac{\ddot{z}}{g} + C_{z_{\ddot{\theta}}}\frac{\ddot{\theta}\bar{c}}{2g} \tag{7-1}$$

The $\dot{a}$ -derivatives are not obtained from the quasi-steady considerations here and will not be discussed further. The rotations of the mean axis in the restrained longitudinal case are defined in terms of rotational derivatives defined by Rodden and Love (1985) [Reference 51].

$$\alpha_m = \alpha_{m_o} + \alpha_{m_\alpha}\alpha + \alpha_{m_\delta}\delta_e + \alpha_{m_q}\frac{q\bar{c}}{2V} + \alpha_{m_{\dot{\alpha}}}\frac{\dot{\alpha}\bar{c}}{2V} + \alpha_{m_{\ddot{z}}}\frac{\ddot{z}}{g} + \alpha_{m_{\ddot{\theta}}}\frac{\ddot{\theta}\bar{c}}{2g} \tag{7-2}$$

Again, the $\dot{a}$ -term will not be discussed further. In the unrestrained case, all inertial derivatives vanish because their effects appear in the remaining derivatives, and the mean axis rotations do not have to be considered in the equations of motion.

Six sets of stability derivatives are generated for the system for each flight condition:

- Rigid unsplined
- Rigid splined
- Elastic restrained at the SUPORTed degrees of freedom
- Elastic unrestrained
- Inertia Restrained
- Inertia Unrestrained

Before the stability derivatives are tabulated, the transformation from the basic to the reference coordinates is shown. This transformation provides a check on the input of the aerodynamic reference coordinate system for the stability derivatives. The stability derivatives for the rigid and elastic vehicle are shown next. The rigid derivatives are those that are obtained while neglecting elastic deformation of the vehicle. These derivatives are presented in two ways: unsplined and splined coefficients, which provide checks on the splining. The unsplined coefficients are based on all of the boxes in the aerodynamic model and are independent of the spline. Usually, the two sets of coefficients are nearly identical unless there is an error in the spline input, such as not including all of the boxes. However, there may be situations where some boxes intentionally may not be connected to the spline, as in the case when no motion of certain boxes is desired.

The stability derivatives are summarized in Table 7-1. For the first dynamic pressure, $\bar{q} = Q = 40 \text{ psf}$, the rigid and elastic coefficients are all quite close except that the inertial derivatives have finite values for the low dynamic pressure. In the rigid case, the inertial derivatives vanish, but in the limit of zero dynamic pressure, the flexible inertial derivatives remain finite. By virtue of the definitions of the inertial derivatives in (7-1), the printed output values corresponding to unit $\text{URDD5} = \ddot{\theta}/g$ must be divided by $\bar{c}/2 = 5.0 \text{ ft}$. The inertial derivatives are absorbed into the basic stability derivatives in the unrestrained case. The aerodynamic center for each loading may be found by dividing its moment coefficient by its lift coefficient and multiplying by the reference chord, for example, for the angle of attack α loading in unrestrained flight $x_{a.c.} = -C_{m_\alpha}\bar{c}/C_{z_\alpha} = 2.835 \text{ ft}$ aft of GRID 90 at low $\bar{q}$.

Hinge Moment Derivatives

Hinge moment coefficient output shows the moment produced at the control surface hinge line due to each of the aerodynamic extra points

Mean Axis Deformation

The mean axis translations and rotations for the SUPORT degrees of freedom follow next in the output and are shown as INTERMEDIATE MATRIX... HP. The rotational derivatives are presented in the second row (that is, printed in the second column shown). These derivatives are only associated with the restrained case, since they must be included in the equations of motion that utilize restrained stability derivatives, as discussed by Rodden and Love (1985) [Reference 51]. Equations of motion relative to the SUPORT using unrestrained stability derivatives are already expressed in terms of mean axis rotations.

The mean axis rotational derivatives are also summarized in Table 7-1. The derivative α_{m_α} is obtained by adding 1.0 to the tabulated value, and the derivative $\alpha_{m_{\ddot{\theta}}}$ is obtained by dividing by $\bar{c}/2 = 5.0 \text{ ft}$.

Table 7-1 Subsonic Derivatives for Example FSW Airplane

Derivative	Value for Rigid Airplane	Restrained Value at $\bar{q}$ = 40 psf	Unrestrained Value at $\bar{q}$ = 40 psf	Restrained Value at $\bar{q}$ = 1200 psf	Unrestrained Value at $\bar{q}$ = 1200 psf
C_{z_o}	-0.008421	-0.008464	-0.008509	-0.010332	-0.012653
C_{m_o}	-0.006008	-0.006031	-0.006064	-0.007074	-0.008678
C_{z_α}	-5.071	-5.103	-5.127	-6.463	-7.772
C_{m_α}	-2.871	-2.889	-2.907	-3.667	-4.577
$C_{z_{\delta_e}}$	-0.2461	-0.2538	-0.2520	-0.5430	-0.5219
$C_{m_{\delta_e}}$	0.5715	0.5667	0.5678	0.3860	0.3956
C_{z_q}	-12.074	-12.087	-12.158	-12.856	-16.100
C_{m_q}	-9.954	-9.956	-10.007	-10.274	-12.499
$C_{z_{\ddot{z}}}$	0.0	0.003154	-	0.003634	-
$C_{m_{\ddot{z}}}$	0.0	0.002369	-	0.002624	-
$C_{z_{\ddot{\theta}}}$	0.0	0.01181	-	0.01449	-
$C_{m_{\ddot{\theta}}}$	0.0	0.007900	-	0.009404	-
α_{m_o}	-	-0.000004062	-	-0.0001419	-
α_{m_α}	-	0.9980	-	0.9251	-
$\alpha_{m_{\delta_e}}$	-	0.0003336	-	0.006420	-
α_{m_q}	-	-0.006942	-	-0.2136	-
$\alpha_{m_{\ddot{z}}}$	-	-0.0001624	-	-0.0001108	-
$\alpha_{m_{\ddot{\theta}}}$	-	-0.001641	-	-0.001457	-

The level flight trim solution follows the mean axis rotations. For the low speed condition, the angle of attack of the structural axis is necessarily high, $ANGLEA = \alpha = 0.169191 \text{ rad} = 9.69 \text{ deg}$, and the corresponding canard incidence is $ELEV = \delta_e = 0.492457 \text{ rad} = 28.22 \text{ deg}$.

Following the trim results, the listing shows default or user specified limits on control surfaces and compares them with the actual trim values.

The Structural and Aerodynamic Total Vehicle Coefficients which follow provide insight on the various loadings on the vehicle and how they balance one another. A description of this output is provided in Hinge Moment and Total Vehicle Coefficients.

The aerodynamic pressure and load data follow the trim solution. The pressure coefficients on each box are also high at the high angle of attack and low dynamic pressure. The pressures and box normal forces balance the weight of the airplane. The aerodynamic moments are taken about the midchord of each box: at subsonic speeds the box force acts at the box quarter-chord and causes a moment about the box reference midchord; at supersonic speeds the box force acts at the box midchord and results in a zero moment on each box.

The remainder of the aeroelastic output for the first subcase in concerned with monitor points. In this case, the monitor point output is in the following order:

- Structural MONPNT1
- Structural MONPNT2
- Structural MONDSP1
- Aerodynamic MONPNT1
- MONCNM
- Aerodynamic MONDSP1

The structural MONPNT1's begin with an internal monitor point that is always generated with the name AEROGS2D (default value for the AECONFIG case control) and label Full Vehicle Integrated Loads. It provides a load summation in six directions about a point that is the origin of the aerodynamic coordinate system (the reference coordinate system on the AEROS entry). A notable result in this table is that the elastic load in the z direction is -8000.0 which is equal to the weight of the vehicle in 1G flight. The second structural monitor point is user generated with the name WINSTRC. Recall that this monitor point invokes only the grid points on the wing and it shows a z load of 5900 in coordinate system 2 that has a z component that is in the opposite direction of the aerodynamic coordinate system as well as an origin that is displayed in the x-direction. The final structural MONPNT1 has name WINGSUM and is actually output from a MONSUM request that is reported as a structural MONPNT1 by convention. This is a contrived result that differences structural loads on the wing from the aerodynamic ones. It is seen that the two monitor points do not sum to exactly zero, reflecting how the loads on the wing are not the total story for the complete vehicle.

The output now continues with MONPT2 results. Four MONPNT2 entries are provided to give a quick look at stresses in the two primary pieces of structure on the wing. If the results of the MONPNT2 are compared with the standard stress output shown later, it is seen that the numbers agree very well.

Structural MONDSP1 results appear next and this presents an average of the displacement at the structural tip.

The remaining results are aerodynamic, beginning with another internally generated monitor point that sums the aerodynamic loads on the entire vehicle. It is seen that the elastic components of this aerodynamic component matches the structural ones closely. The next aerodynamic monitor is another internally generated one and shows the hinge moment on the elevator produced by the airloads. The aerodynamic monitor point with the name WINGAERO sums the loads from all the wing aero boxes. This is the monitor point that is summed with WINGSTRC to provide the WINGSUM results.

The MONCNCM with name CNCMCAN provides results for the two aerodynamic strips on the canard as shown in Figure 7-1. YS and ZS provide y and z locations of the strip while XREF indicates the location about which the moments are computed in the coordinate system 1 (the aerodynamic coordinate system). The force results are normalized by dynamic pressure times the area (qS) of the strip while the moment is normalized by qS times the chord. MONCNCM with name CMCNWING provides similar stripwise results for the eight strips on the wing.

Finally, an aerodynamic MONDSP1 with name RWTAD provides averaged displacement output based on the aerodynamic displacements of the eight outboard aerodynamic boxes.

The restrained and unrestrained derivatives for the second dynamic pressure, $\bar{q} = 1200\ \mathrm{psf}$, are shown next and are also summarized in Table 7-1. In this case, the aerodynamic center in unrestrained flight has moved slightly aft to $x_{a.c.} = 2.945\ \mathrm{ft}$ behind GRID 90. The level flight trim solution is given next. The angle of attack of the structural axis through GRID 90 is

$\alpha = \mathrm{ANGLEA} = 0.001373\ \mathrm{rad} = 0.079\ \mathrm{deg}$ and

$\delta_e = \mathrm{ELEV} = 0.01932\ \mathrm{rad} = 1.107\ \mathrm{deg}$.

Following the trim solution are the aerodynamic pressure coefficients and pressures on each aerodynamic box in the trimmed condition and then the aerodynamic forces and moments about the 50% chord of each box. The aeroelastic redistribution of loads with increasing dynamic pressure is seen by comparing the pressures and normal forces between Subcases 1 and 2. Note that significant output has been deleted from Listing 7-2 but you can see complete results by running the job.

The third subcase is supersonic level flight at $m = 1.3$ and $\bar{q} = 1151\ \mathrm{psf}$. The supersonic stability derivatives are output next and are summarized in Table 7-2. The aerodynamic center has moved aft to 4.088 ft behind GRID 90. Because of the wing incidence of 0.1 deg, the supersonic angle of attack of the structural axis is negative, $\alpha = \mathrm{ANGLEA} = -0.0005118\ \mathrm{rad} = -0.003\ \mathrm{deg}$, and the canard angle is $\delta_e = \mathrm{ELEV} = 0.03027\ \mathrm{rad} = 1.734\ \mathrm{deg}$.

The supersonic load distribution is different from the subsonic distribution as can be seen by comparing the pressures and normal forces between Subcases 2 and 3. The output file concludes with standard structural data recovery (not shown in Listing 7-2). The structural deformations of all the grid points relative to the SUPORT point, GRID 90, are output for the three subcases.

Finally, the element loads and stresses are given for the three subcases. The loads include bending moments, shears, and torques. Some of the stresses are high for the arbitrarily chosen cross-sectional properties.

Table 7-2 Supersonic Derivatives for Example FSW Airplane

Derivative	Value for Rigid Airplane	Restrained Value at $\bar{q}$ = 1151 psf	Unrestrained Value at $\bar{q}$ = 1151 psf
C_{z_o}	-0.007352	-0.007172	-0.008557
C_{m_o}	-0.007195	-0.006959	-0.008270
C_{z_α}	-4.847	-4.948	-5.783
C_{m_α}	-3.885	-3.933	-4.728
$C_{z_{\delta_e}}$	-0.6346	-0.8386	-0.8802
$C_{m_{\delta_e}}$	0.2378	0.05436	0.010545
C_{z_q}	-9.055	-7.611	-9.305
C_{m_q}	-10.149	-8.769	-10.360
$C_{z_{\ddot{z}}}$	0.0	0.002447	-
$C_{m_{\ddot{z}}}$	0.0	0.002470	-

Main Index

Derivative	Value for Rigid Airplane	Restrained Value at $\bar{q}$ = 1151 psf	Unrestrained Value at $\bar{q}$ = 1151 psf
$C_{z_{\ddot{\theta}}}$	0.0	0.010366	-
$C_{m_{\ddot{\theta}}}$	0.0	0.009444	-
α_{m_o}	-	-0.0001459	-
α_{m_α}	-	0.9165	-
$\alpha_{m_{\delta_e}}$	-	0.00009123	-
α_{m_q}	-	-0.1875	-
$\alpha_{m_{\ddot{z}}}$	-	-0.0001120	-
$\alpha_{m_{\ddot{\theta}}}$	-	-0.001448	-

Listing 7-2 Output for FSW Airplane in Level Flight

```
N O N - D I M E N S I O N A L   S T A B I L I T Y   A N D   C O N T R O L   D E R I V A T I V E   C O E F F I C I E N T S

                         CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
                                         MACH = 9.0000E-01                        Q = 4.0000E+01
                         CHORD = 1.0000E+01           SPAN = 4.0000E+01            AREA = 2.0000E+02


                TRANSFORMATION FROM BASIC TO REFERENCE COORDINATES:

              { X }        [ -1.0000   0.0000   0.0000  ] { X }         { 1.5000E+01 }
              { Y }    =   [  0.0000   1.0000   0.0000  ] { Y }      +  { 0.0000E+00 }
              { Z }REF     [  0.0000   0.0000  -1.0000  ] { Z }BAS      { 0.0000E+00 }

CONTROLLER STATE: INTERCEPT ONLY, ALL CONTROLLERS ARE ZERO

    TRIM VARIABLE   COEFFICIENT             RIGID                         ELASTIC                          INERTIAL
                                  UNSPLINED        SPLINED        RESTRAINED     UNRESTRAINED      RESTRAINED     UNRESTRAINED

    REF. COEFF.      CX         0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                     CY         0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                     CZ        -8.420786E-03   -8.420786E-03    -8.463757E-03   -8.508834E-03     0.000000E+00   -8.508834E-03
                     CMX        0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                     CMY       -6.008128E-03   -6.008128E-03    -6.031396E-03   -6.063684E-03     0.000000E+00   -6.063684E-03
                     CMZ        0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00

    ANGLEA           CX         0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                     CY         0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                     CZ        -5.070975E+00   -5.070975E+00    -5.103213E+00   -5.127250E+00     0.000000E+00   -5.127250E+00
                     CMX        0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                     CMY       -2.870931E+00   -2.870931E+00    -2.889137E+00   -2.906502E+00     0.000000E+00   -2.906502E+00
                     CMZ        0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00

    PITCH            CX         0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                     CY         0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                     CZ        -1.207429E+01   -1.207429E+01    -1.208659E+01   -1.215825E+01     0.000000E+00   -1.215825E+01
                     CMX        0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                     CMY       -9.953998E+00   -9.953998E+00    -9.956322E+00   -1.000715E+01     0.000000E+00   -1.000715E+01
                     CMZ        0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
```

Main Index

Listing 7-2 Output for FSW Airplane in Level Flight (Continued)

```
     URDD3            CX        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                      CY        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                      CZ        0.000000E+00    0.000000E+00    3.154313E-03    0.000000E+00    1.000000E+00    0.000000E+00
                      CMX       0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                      CMY       0.000000E+00    0.000000E+00    2.368632E-03    0.000000E+00    2.181625E-01    0.000000E+00
                      CMZ       0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00

     URDD5            CX        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                      CY        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                      CZ        0.000000E+00    0.000000E+00    5.904780E-02    0.000000E+00    2.181625E+00    0.000000E+00
                      CMX       0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                      CMY       0.000000E+00    0.000000E+00    3.950050E-02    0.000000E+00    1.163713E+01    0.000000E+00
                      CMZ       0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00

     ELEV             CX        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                      CY        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                      CZ       -2.461394E-01   -2.461394E-01   -2.537563E-01   -2.519653E-01    0.000000E+00   -2.519653E-01
                      CMX       0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                      CMY       5.715301E-01    5.715301E-01    5.666561E-01    5.677910E-01    0.000000E+00    5.677910E-01
                      CMZ       0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
  N O N - D I M E N S I O N A L    H I N G E    M O M E N T    D E R I V A T I V E    C O E F F I C I E N T S


                        CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
                                        MACH = 9.0000E-01                    Q = 4.0000E+01

          CONTROL SURFACE = ELEV         REFERENCE CHORD LENGTH =  1.000000E+00     REFERENCE AREA =  1.000000E+00

              TRIM VARIABLE             RIGID                         ELASTIC                             INERTIAL
                                                            RESTRAINED      UNRESTRAINED         RESTRAINED      UNRESTRAINED
              AT REFERENCE        -1.541222E-01             -1.553415E-01   -1.559161E-01         0.000000E+00    0.000000E+00
              ANGLEA               3.103143E+01              3.020692E+01    2.989496E+01         0.000000E+00    0.000000E+00
              PITCH               -6.124346E+02             -6.132635E+02   -6.141365E+02         0.000000E+00    0.000000E+00
              URDD3                0.000000E+00              4.527646E-02    0.000000E+00         0.000000E+00    0.000000E+00
              URDD5                0.000000E+00              5.787790E-01    0.000000E+00         0.000000E+00    0.000000E+00
              ELEV                 1.193384E+02              1.192125E+02    1.192298E+02         0.000000E+00    0.000000E+00
                                                    INTERMEDIATE MATRIX ... HP

                                                              COLUMN      1
      1                                              6.451200E-05      -4.062406E-06                                              2

                                                              COLUMN      2
      1                                              3.659248E-02      -1.994000E-03                                              2

                                                              COLUMN      3
      1                                              9.315132E-02      -6.941709E-03                                              2

                                                              COLUMN      4
      1                                             -6.349168E-03       1.624086E-04                                              2

                                                              COLUMN      5
      1                                             -1.459011E-02       8.205779E-03                                              2

                                                              COLUMN      6
      1                                             -3.707938E-04       3.336262E-04                                              2

                                                    INTERMEDIATE MATRIX ... UX
```

Listing 7-2 Output for FSW Airplane in Level Flight (Continued)

```
                                        COLUMN      1
     1        1.000000E+00       1.691910E-01       0.000000E+00      -1.000000E+00       0.000000E+00       4.924567E-01        6

                              INTERMEDIATE MATRIX ... UXIFV


                                        COLUMN      1
     1        3.383523E-01       1.691910E-01       0.000000E+00       4.924567E-01      -1.000000E+00       0.000000E+00        6


                    A E R O S T A T I C   D A T A   R E C O V E R Y   O U T P U T   T A B L E S
                 CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
                                  MACH = 9.000000E-01                 Q = 4.000000E+01
                 CHORD = 1.0000E+01           SPAN = 4.0000E+01           AREA = 2.0000E+02

     TRIM ALGORITHM USED: LINEAR TRIM SOLUTION WITHOUT REDUNDANT CONTROL SURFACES.


                                     AEROELASTIC TRIM VARIABLES

                       ID     LABEL                 TYPE        TRIM STATUS      VALUE OF UX

                              INTERCEPT          RIGID BODY          FIXED      1.000000E+00
                      501     ANGLEA             RIGID BODY           FREE      1.691910E-01  RADIANS
                      502     PITCH              RIGID BODY          FIXED      0.000000E+00  NONDIMEN. RATE
                      503     URDD3              RIGID BODY          FIXED     -1.000000E+00  LOAD FACTOR
                      504     URDD5              RIGID BODY          FIXED      0.000000E+00  RAD/S/S PER G
                      505     ELEV           CONTROL SURFACE          FREE      4.924567E-01  RADIANS


                            CONTROL SURFACE POSITION AND HINGE MOMENT RESULTS

                 ACTIVE LIMITS ARE FLAGGED WITH AN (A),  VIOLATED LIMITS ARE FLAGGED WITH A (V).

                                 POSITION                                         HINGE MOMENT
     CONTROL SURFACE     LOWER LIMIT     VALUE        UPPER LIMIT       LOWER LIMIT     VALUE        UPPER LIMIT
         ELEV          -1.570796E+00   4.924567E-01   1.570796E+00           N/A       2.544685E+03       N/A

                    A E R O S T A T I C   D A T A   R E C O V E R Y   O U T P U T   T A B L E S
                 CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
                                  MACH = 9.000000E-01                 Q = 4.000000E+01
                 CHORD = 1.0000E+01           SPAN = 4.0000E+01           AREA = 2.0000E+02


                           TRANSFORMATION FROM REFERENCE TO WIND AXES:
                      ANGLE OF ATTACK    =  1.691910E-01 RADIANS (      9.693934 DEGREES)
                      ANGLE OF SIDESLIP =  0.000000E+00 RADIANS (      0.000000 DEGREES)

                            { X }          [ -0.985721  0.000000 -0.168385 ]  { X }
                            { Y }          [  0.000000  1.000000  0.000000 ]  { Y }
                            { Z }WIND =    [  0.168385  0.000000 -0.985721 ]  { Z }REF


   STRUCTURAL  MONITOR POINT TOTAL VEHICLE COEFFICIENTS:
         AXIS         RIGID AIR  +  RESTRAINED INCR.  -  INERTIAL  +   RIGID-APPLIED + RESTRAINED INCR.  =  BALANCE
         ----         ---------     ----------------     --------      -------------   ----------------     -------
   BODY  CX          0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00
   WIND  CD          1.662966E-01     2.088429E-03     1.683850E-01     0.000000E+00     0.000000E+00     0.000000E+00

   BODY  CY          0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00
   WIND  CY-WIND     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00
```

Listing 7-2 Output for FSW Airplane in Level Flight (Continued)

```
BODY  CZ        -9.875973E-01   -1.240270E-02   -1.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
WIND  CL         9.734957E-01    1.222561E-02    9.857213E-01    0.000000E+00    0.000000E+00    0.000000E+00

BODY  CMX       -1.908003E-01   -2.842972E-03   -6.250000E-02    0.000000E+00    0.000000E+00   -1.311432E-01
WIND  CM-ROLL    1.880759E-01    2.802378E-03    6.160758E-02    0.000000E+00    0.000000E+00    1.292707E-01

BODY  CMY       -2.102901E-01   -7.872351E-03   -2.181625E-01    0.000000E+00    0.000000E+00    0.000000E+00
WIND  CM-PITCH  -2.102901E-01   -7.872351E-03   -2.181625E-01    0.000000E+00    0.000000E+00    0.000000E+00

BODY  CMZ        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
WIND  CM-YAW    -3.212790E-02   -4.787138E-04   -1.052406E-02    0.000000E+00    0.000000E+00   -2.208255E-02


AERODYNAMIC MONITOR POINT TOTAL VEHICLE COEFFICIENTS:
      AXIS         RIGID AIR  +  RESTRAINED INCR.  -  INERTIAL  +   RIGID-APPLIED + RESTRAINED INCR.  =  BALANCE
      ----         ---------     ----------------     --------      -------------   ----------------     -------
BODY  CX         0.000000E+00    0.000000E+00         N/A              N/A         0.000000E+00    0.000000E+00
WIND  CD         1.662966E-01    2.088429E-03         N/A              N/A         0.000000E+00    1.683850E-01

BODY  CY         0.000000E+00    0.000000E+00         N/A              N/A         0.000000E+00    0.000000E+00
WIND  CY-WIND    0.000000E+00    0.000000E+00         N/A              N/A         0.000000E+00    0.000000E+00

BODY  CZ        -9.875973E-01   -1.240270E-02         N/A              N/A         0.000000E+00   -1.000000E+00
WIND  CL         9.734957E-01    1.222561E-02         N/A              N/A         0.000000E+00    9.857213E-01

BODY  CMX       -2.113756E-01   -2.870647E-03         N/A              N/A         0.000000E+00   -2.142462E-01
WIND  CM-ROLL    2.083574E-01    2.829658E-03         N/A              N/A         0.000000E+00    2.111871E-01

BODY  CMY       -2.102901E-01   -7.872351E-03         N/A              N/A         0.000000E+00   -2.181625E-01
WIND  CM-PITCH  -2.102901E-01   -7.872351E-03         N/A              N/A         0.000000E+00   -2.181625E-01

BODY  CMZ        0.000000E+00    0.000000E+00         N/A              N/A         0.000000E+00    0.000000E+00
WIND  CM-YAW    -3.559247E-02   -4.833739E-04         N/A              N/A         0.000000E+00   -3.607585E-02


                          A E R O S T A T I C   D A T A   R E C O V E R Y   O U T P U T   T A B L E S
                    CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
                                      MACH = 9.000000E-01                Q = 4.000000E+01
                    CHORD = 1.0000E+01           SPAN = 4.0000E+01            AREA = 2.0000E+02


                                         AERODYNAMIC PRESSURES ON THE AERODYNAMIC ELEMENTS

                                                          AERODYNAMIC PRES.       AERODYNAMIC
                                        GRID    LABEL        COEFFICIENTS           PRESSURES
                                          1      LS          4.784523E+00         1.913809E+02
                                          2      LS          8.703240E-01         3.481296E+01
                                          3      LS          3.553293E-01         1.421317E+01
                                          4      LS          2.838615E-01         1.135446E+01
                                          5      LS          3.788153E+00         1.515261E+02
                                          6      LS          6.253395E-01         2.501358E+01
                                          7      LS          2.709479E-01         1.083792E+01
                                          8      LS          2.500269E-01         1.000108E+01
                                          9      LS         -1.200071E+00        -4.800282E+01
                                         10      LS         -5.319485E-02        -2.127794E+00
```

Listing 7-2 Output for FSW Airplane in Level Flight (Continued)

```
                              11     LS          3.286699E-02        1.314679E+00
                              12     LS          2.254037E-02        9.016147E-01
                              13     LS         -7.479146E-03       -2.991658E-01
                              14     LS         -1.702175E-03       -6.808700E-02
                              15     LS          4.540965E-02        1.816386E+00
                              16     LS          3.006160E-02        1.202464E+00
                              17     LS          4.197103E+00        1.678841E+02
                              18     LS          4.496374E-01        1.798550E+01
                              19     LS          1.206772E-01        4.827087E+00
                              20     LS          4.692961E-02        1.877184E+00
                              21     LS          3.132609E+00        1.253044E+02
                              22     LS          1.012216E+00        4.048863E+01
                              23     LS          2.907212E-01        1.162885E+01
                              24     LS          9.219132E-02        3.687653E+00
                              25     LS          2.432680E+00        9.730719E+01
                              26     LS          1.065420E+00        4.261680E+01
                              27     LS          4.645950E-01        1.858380E+01
                              28     LS          1.603586E-01        6.414344E+00
                              29     LS          1.921810E+00        7.687242E+01
                              30     LS          9.217110E-01        3.686844E+01
                              31     LS          5.207017E-01        2.082807E+01
                              32     LS          2.245566E-01        8.982263E+00
                              33     LS          1.467171E+00        5.868684E+01
                              34     LS          7.182634E-01        2.873053E+01
                              35     LS          4.659270E-01        1.863708E+01
                              36     LS          2.473708E-01        9.894831E+00
                              37     LS          9.616058E-01        3.846423E+01
                              38     LS          4.610366E-01        1.844146E+01
                              39     LS          3.229629E-01        1.291852E+01
                              40     LS          2.048081E-01        8.192326E+00

     *** LABEL NOTATIONS:  LS = LIFTING SURFACE,   ZIB = Z INTERFERENCE BODY ELEMENT,  ZSB = Z SLENDER BODY ELEMENT,
                                                   YIB = Y INTERFERENCE BODY ELEMENT,  YSB = Y SLENDER BODY ELEMENT.

                     A E R O S T A T I C   D A T A   R E C O V E R Y   O U T P U T   T A B L E S
               CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
                                 MACH = 9.000000E-01              Q = 4.000000E+01
               CHORD = 1.0000E+01           SPAN = 4.0000E+01            AREA = 2.0000E+02


                                  AERODYNAMIC FORCES ON THE AERODYNAMIC ELEMENTS

  GROUP  GRID ID  LABEL        T1                T2                T3                R1                R2                R3
     1     1000    LS     0.000000E+00      0.000000E+00      1.196131E+03      0.000000E+00      7.475817E+02      0.000000E+00
     1     1001    LS     0.000000E+00      0.000000E+00      2.175810E+02      0.000000E+00      1.359881E+02      0.000000E+00
     1     1002    LS     0.000000E+00      0.000000E+00      8.883233E+01      0.000000E+00      5.552021E+01      0.000000E+00
     1     1003    LS     0.000000E+00      0.000000E+00      7.096537E+01      0.000000E+00      4.435335E+01      0.000000E+00
     1     1004    LS     0.000000E+00      0.000000E+00      9.470383E+02      0.000000E+00      5.918990E+02      0.000000E+00
     1     1005    LS     0.000000E+00      0.000000E+00      1.563349E+02      0.000000E+00      9.770929E+01      0.000000E+00
     1     1006    LS     0.000000E+00      0.000000E+00      6.773698E+01      0.000000E+00      4.233561E+01      0.000000E+00
     1     1007    LS     0.000000E+00      0.000000E+00      6.250674E+01      0.000000E+00      3.906671E+01      0.000000E+00
     1     1100    LS     0.000000E+00      0.000000E+00     -3.000177E+02      0.000000E+00     -1.875110E+02      0.000000E+00
     1     1101    LS     0.000000E+00      0.000000E+00     -1.329871E+01      0.000000E+00     -8.311696E+00      0.000000E+00
     1     1102    LS     0.000000E+00      0.000000E+00      8.216746E+00      0.000000E+00      5.135467E+00      0.000000E+00
     1     1103    LS     0.000000E+00      0.000000E+00      5.635092E+00      0.000000E+00      3.521932E+00      0.000000E+00
     1     1104    LS     0.000000E+00      0.000000E+00     -1.869786E+00      0.000000E+00     -1.168617E+00      0.000000E+00
     1     1105    LS     0.000000E+00      0.000000E+00     -4.255438E-01      0.000000E+00     -2.659649E-01      0.000000E+00
```

Listing 7-2 Output for FSW Airplane in Level Flight (Continued)

```
1     1106  LS     0.000000E+00     0.000000E+00     1.135241E+01     0.000000E+00     7.095257E+00     0.000000E+00
1     1107  LS     0.000000E+00     0.000000E+00     7.515401E+00     0.000000E+00     4.697125E+00     0.000000E+00
1     1108  LS     0.000000E+00     0.000000E+00     1.049276E+03     0.000000E+00     6.557973E+02     0.000000E+00
1     1109  LS     0.000000E+00     0.000000E+00     1.124094E+02     0.000000E+00     7.025585E+01     0.000000E+00
1     1110  LS     0.000000E+00     0.000000E+00     3.016929E+01     0.000000E+00     1.885581E+01     0.000000E+00
1     1111  LS     0.000000E+00     0.000000E+00     1.173240E+01     0.000000E+00     7.332751E+00     0.000000E+00
1     1112  LS     0.000000E+00     0.000000E+00     7.831523E+02     0.000000E+00     4.894702E+02     0.000000E+00
1     1113  LS     0.000000E+00     0.000000E+00     2.530539E+02     0.000000E+00     1.581587E+02     0.000000E+00
1     1114  LS     0.000000E+00     0.000000E+00     7.268030E+01     0.000000E+00     4.542519E+01     0.000000E+00
1     1115  LS     0.000000E+00     0.000000E+00     2.304783E+01     0.000000E+00     1.440489E+01     0.000000E+00
1     1116  LS     0.000000E+00     0.000000E+00     6.081700E+02     0.000000E+00     3.801062E+02     0.000000E+00
1     1117  LS     0.000000E+00     0.000000E+00     2.663550E+02     0.000000E+00     1.664719E+02     0.000000E+00
1     1118  LS     0.000000E+00     0.000000E+00     1.161487E+02     0.000000E+00     7.259297E+01     0.000000E+00
1     1119  LS     0.000000E+00     0.000000E+00     4.008965E+01     0.000000E+00     2.505603E+01     0.000000E+00
1     1120  LS     0.000000E+00     0.000000E+00     4.804526E+02     0.000000E+00     3.002829E+02     0.000000E+00
1     1121  LS     0.000000E+00     0.000000E+00     2.304277E+02     0.000000E+00     1.440173E+02     0.000000E+00
1     1122  LS     0.000000E+00     0.000000E+00     1.301754E+02     0.000000E+00     8.135964E+01     0.000000E+00
1     1123  LS     0.000000E+00     0.000000E+00     5.613914E+01     0.000000E+00     3.508696E+01     0.000000E+00
1     1124  LS     0.000000E+00     0.000000E+00     3.667928E+02     0.000000E+00     2.292455E+02     0.000000E+00
1     1125  LS     0.000000E+00     0.000000E+00     1.795658E+02     0.000000E+00     1.122286E+02     0.000000E+00
1     1126  LS     0.000000E+00     0.000000E+00     1.164818E+02     0.000000E+00     7.280110E+01     0.000000E+00
1     1127  LS     0.000000E+00     0.000000E+00     6.184270E+01     0.000000E+00     3.865168E+01     0.000000E+00
1     1128  LS     0.000000E+00     0.000000E+00     2.404015E+02     0.000000E+00     1.502509E+02     0.000000E+00
1     1129  LS     0.000000E+00     0.000000E+00     1.152591E+02     0.000000E+00     7.203697E+01     0.000000E+00
1     1130  LS     0.000000E+00     0.000000E+00     8.074073E+01     0.000000E+00     5.046296E+01     0.000000E+00
1     1131  LS     0.000000E+00     0.000000E+00     5.120204E+01     0.000000E+00     3.200127E+01     0.000000E+00

  *** LABEL NOTATIONS:  LS = LIFTING SURFACE,   ZSB =  Z SLENDER BODY ELEMENT,  YSB =  Y SLENDER BODY ELEMENT,
                                              ZYSB = ZY SLENDER BODY ELEMENT, EXTA = EXTERNAL AERO.

                      S T R U C T U R A L   M O N I T O R   P O I N T   I N T E G R A T E D   L O A D S
                 CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
                                  MACH = 9.000000E-01                Q = 4.000000E+01

CONTROLLER STATE:
ANGLEA    =   1.6919E-01        URDD3    =  -1.0000E+00        ELEV     =   4.9246E-01

MONITOR POINT NAME = AEROSG2D          COMPONENT =                   CLASS = COEFFICIENT
LABEL = Full Vehicle Integrated Loads
 CP =      100          X =  0.00000E+00          Y =  0.00000E+00          Z =  0.00000E+00          CD =      100

  AXIS      RIGID AIR      ELASTIC REST.      INERTIAL      RIGID APPLIED    REST. APPLIED
  ----    -------------    -------------    -------------    -------------    -------------
   CX     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00
   CY     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00
   CZ    -7.900778E+03    -8.000000E+03    -8.000000E+03     0.000000E+00     0.000000E+00
   CMX   -6.105609E+04    -6.196584E+04    -2.000000E+04     0.000000E+00     0.000000E+00
   CMY   -1.682321E+04    -1.745300E+04    -1.745300E+04     0.000000E+00     0.000000E+00
   CMZ    0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00

MONITOR POINT NAME = WINGSTRC          COMPONENT = WINGSTRC          CLASS = GENERAL
LABEL = WING STRUCTURE
 CP =        2          X =  0.00000E+00          Y =  0.00000E+00          Z =  0.00000E+00          CD =        2
```

Listing 7-2 Output for FSW Airplane in Level Flight (Continued)

```
  AXIS      RIGID AIR       ELASTIC REST.      INERTIAL      RIGID APPLIED     REST. APPLIED
  ----    -------------    -------------    -------------    -------------    -------------
   CX     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00
   CY     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00
   CZ     5.808699E+03     5.899794E+03     2.000000E+03     0.000000E+00     0.000000E+00
   CMX    8.037953E+04     8.155503E+04     2.359401E+04     0.000000E+00     0.000000E+00
   CMY    1.710924E+04     1.732576E+04     8.660160E+02     0.000000E+00     0.000000E+00
   CMZ    0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00

MONITOR POINT NAME = WINGSUM           COMPONENT = **SUM**           CLASS = GENERAL
LABEL = SUMMATION OF WING AERO AND STRUCTURAL LOADS
  CP,X,Y,Z AND CD ARE NOT DEFINED FOR MONITOR RESULTS CREATED FROM A MONSUM

  AXIS      RIGID AIR       ELASTIC REST.      INERTIAL      RIGID APPLIED     REST. APPLIED
  ----    -------------    -------------    -------------    -------------    -------------
   CX     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00
   CY     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00
   CZ    -7.113354E+02    -7.069204E+02    -2.000000E+03     0.000000E+00     0.000000E+00
   CMX    0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00
   CMY   -4.271850E+03    -4.247399E+03    -8.660160E+02     0.000000E+00     0.000000E+00
   CMZ    0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00

               S T R U C T U R A L   I N T E R N A L   M O N I T O R   P O I N T   L O A D S (MONPNT2)
                 CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
                                   MACH = 9.000000E-01                Q = 4.000000E+01

CONTROLLER STATE:
ANGLEA    =    1.6919E-01        URDD3    =   -1.0000E+00        ELEV     =    4.9246E-01

MONITOR POINT NAME = MONPNT2

      VALUE         EID       ETYPE   CLASS   RESPONSE LABEL
  ------------- ----------  -------- -------- -------- ----------------------------------------------------------------
   0.000000E+00        110  CBAR     STRESS   AS       RWIAS   RIGHT WING INBOARD AXIAL STRESS
  -1.669278E+05        110  CBAR     STRESS   SX1A     RWISX1A RIGHT WING INBOARD STRESS
   0.000000E+00        120  CBAR     STRESS   AS       RSOAS   RIGHT WING OUTBOARD AXIAL STRESS
  -8.715058E+04        120  CBAR     STRESS   SX1A     RSOSX1A RIGHT WING OUTBOARD STRESS

                      S T R U C T U R A L   M O N I T O R   P O I N T   D I S P L A C E M E N T S
                 CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
                                   MACH = 9.000000E-01                Q = 4.000000E+01

CONTROLLER STATE:
ANGLEA    =    1.6919E-01        URDD3    =   -1.0000E+00        ELEV     =    4.9246E-01

MONITOR POINT NAME = RWTSD             COMPONENT = RWTSD             CLASS = DISPLACEMENT
LABEL = RIGHT WING TIP STRUCTURAL DISPLACEMENT
 CP =         0          X =  1.06077E+02          Y =  1.80000E+02          Z =  0.00000E+00          CD =         0

  AXIS     ELASTIC REST.
  ----    -------------
   TX     0.000000E+00
   TY     0.000000E+00
   TZ    -9.900897E-02
   RX     9.171065E-04
   RY     3.255694E-03
   RZ     0.000000E+00
```

Listing 7-2 Output for FSW Airplane in Level Flight (Continued)

```
                    A E R O D Y N A M I C   M O N I T O R   P O I N T   I N T E G R A T E D   L O A D S
                CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
                                  MACH = 9.000000E-01                Q = 4.000000E+01

CONTROLLER STATE:
ANGLEA   =   1.6919E-01        URDD3    =  -1.0000E+00        ELEV     =   4.9246E-01

MONITOR POINT NAME = AEROSG2D         COMPONENT =                  CLASS = COEFFICIENT
LABEL = Full Vehicle Integrated Loads
 CP =      100          X =  0.00000E+00          Y =  0.00000E+00          Z =  0.00000E+00          CD =      100

  AXIS      RIGID AIR       ELASTIC REST.
  ----    -------------    -------------
   CX      0.000000E+00     0.000000E+00
   CY      0.000000E+00     0.000000E+00
   CZ     -7.900778E+03    -8.000000E+03
   CMX    -6.764018E+04    -6.855879E+04
   CMY    -1.682321E+04    -1.745300E+04
   CMZ     0.000000E+00     0.000000E+00

MONITOR POINT NAME = ELEV             COMPONENT = 1000             CLASS = HINGE MOMENT
LABEL = ELEV     - Control Surface Hinge Moment
 CP =        1          X =  0.00000E+00          Y =  0.00000E+00          Z =  0.00000E+00          CD =        1

  AXIS      RIGID AIR       ELASTIC REST.
  ----    -------------    -------------
   CMY     2.554605E+03     2.544685E+03

MONITOR POINT NAME = WINGAERO         COMPONENT = WINGAERO         CLASS = GENERAL
LABEL = WING AERO
 CP =        2          X =  0.00000E+00          Y =  0.00000E+00          Z =  0.00000E+00          CD =        2

  AXIS      RIGID AIR       ELASTIC REST.
  ----    -------------    -------------
   CZ      5.097364E+03     5.192874E+03
   CMY     1.283739E+04     1.307836E+04

MONCNCM NAME =       CNCMCAN          INT GROUP ID =     1           CLASS = STRIP
LABEL = NORMAL FORCE AND PITCHING MOMENT COEFFICIENTS AT TRIM
 CP =        1          AERODYNAMIC COORDINATE SYSTEM

                                                                              FORCE                    MOMENT
STRP     YS          ZS         XREF         REFC         REFS        RIGID       ELASTIC      RIGID       ELASTIC

____  __________  __________  __________  ___________  ___________  ___________  ___________  ___________  ___________
   1   1.250E+00   0.000E+00   0.000E+00   1.0000E+01   2.5000E+01   1.5715E+00   1.5735E+00   1.4352E-01   1.4300E-01
   2   3.750E+00   0.000E+00   0.000E+00   1.0000E+01   2.5000E+01   1.2319E+00   1.2336E+00   1.1194E-01   1.1147E-01

MONCNCM NAME =       CNCMWING         INT GROUP ID =     1           CLASS = STRIP
LABEL = NORMAL FORCE AND PITCHING MOMENT COEFFICIENTS AT TRIM
 CP =        1          AERODYNAMIC COORDINATE SYSTEM

                                                                              FORCE                    MOMENT
```

Listing 7-2 Output for FSW Airplane in Level Flight (Continued)

```
STRP     YS          ZS         XREF         REFC         REFS         RIGID       ELASTIC      RIGID       ELASTIC
 ____  __________  __________  __________  ___________  ___________  ___________  ___________  ___________  ___________
    3   1.250E+00   0.000E+00   1.428E+01   1.0000E+01   2.5000E+01  -3.1044E-01  -2.9946E-01  -6.2362E-02  -6.1160E-02
    4   3.750E+00   0.000E+00   1.283E+01   1.0000E+01   2.5000E+01   4.9705E-03   1.6572E-02  -9.2160E-03  -8.0990E-03
    5   6.250E+00   0.000E+00   1.139E+01   1.0000E+01   2.5000E+01   1.1896E+00   1.2036E+00   1.7237E-01   1.7369E-01
    6   8.750E+00   0.000E+00   9.948E+00   1.0000E+01   2.5000E+01   1.1173E+00   1.1319E+00   9.4866E-02   9.5348E-02
    7   1.125E+01   0.000E+00   8.505E+00   1.0000E+01   2.5000E+01   1.0168E+00   1.0308E+00   3.8398E-02   3.8538E-02
    8   1.375E+01   0.000E+00   7.061E+00   1.0000E+01   2.5000E+01   8.8463E-01   8.9719E-01   3.4615E-03   3.4250E-03
    9   1.625E+01   0.000E+00   5.618E+00   1.0000E+01   2.5000E+01   7.1419E-01   7.2468E-01  -1.3503E-02  -1.3636E-02
   10   1.875E+01   0.000E+00   4.175E+00   1.0000E+01   2.5000E+01   4.8032E-01   4.8760E-01  -1.6023E-02  -1.6161E-02

                              A E R O D Y N A M I C   M O N I T O R   P O I N T   D I S P L A C E M E N T S
                         CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
                                           MACH = 9.000000E-01                Q = 4.000000E+01

        CONTROLLER STATE:
        ANGLEA    =    1.6919E-01        URDD3    =   -1.0000E+00        ELEV     =    4.9246E-01

        MONITOR POINT NAME = RWTAD             COMPONENT = RWTAD             CLASS = DISPLACEMENT
        LABEL = RIGHT WING TIP AERO DISPLACMENT
         CP =         0          X =   7.14359E+01          Y =   2.40000E+02          Z =   0.00000E+00          CD =        0

          AXIS     ELASTIC REST.
          ----    -------------
           TZ     7.875689E-02
           RY     3.258321E-03

0     HALF-SPAN MODEL, STATIC SYMMETRIC LOADING                                                          SUBCASE 2

    N O N - D I M E N S I O N A L   S T A B I L I T Y   A N D   C O N T R O L   D E R I V A T I V E   C O E F F I C I E N T S

                         CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
                                         MACH = 9.0000E-01                   Q = 1.2000E+03
                         CHORD = 1.0000E+01           SPAN = 4.0000E+01           AREA = 2.0000E+02


                TRANSFORMATION FROM BASIC TO REFERENCE COORDINATES:

             { X }        [ -1.0000    0.0000    0.0000  ]  { X }         { 1.5000E+01 }
             { Y }    =   [  0.0000    1.0000    0.0000  ]  { Y }      +  { 0.0000E+00 }
             { Z }REF     [  0.0000    0.0000   -1.0000  ]  { Z }BAS      { 0.0000E+00 }


    CONTROLLER STATE: INTERCEPT ONLY, ALL CONTROLLERS ARE ZERO

    TRIM VARIABLE   COEFFICIENT              RIGID                          ELASTIC                          INERTIAL
                                  UNSPLINED         SPLINED        RESTRAINED      UNRESTRAINED      RESTRAINED      UNRESTRAINED

    REF. COEFF.       CX          0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00
                      CY          0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00
                      CZ         -8.420786E-03    -8.420786E-03    -1.033208E-02    -1.265279E-02     0.000000E+00    -1.265279E-02
                      CMX         0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00
                      CMY        -6.008128E-03    -6.008128E-03    -7.073892E-03    -8.678376E-03     0.000000E+00    -8.678376E-03
                      CMZ         0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00
    ANGLEA            CX          0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00
                      CY          0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00
                      CZ         -5.070975E+00    -5.070975E+00    -6.462927E+00    -7.771567E+00     0.000000E+00    -7.771567E+00
                      CMX         0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00
                      CMY        -2.870931E+00    -2.870931E+00    -3.667061E+00    -4.576803E+00     0.000000E+00    -4.576803E+00
                      CMZ         0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00
```

Listing 7-2 Output for FSW Airplane in Level Flight (Continued)

```
     PITCH            CX         0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                      CY         0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                      CZ        -1.207429E+01   -1.207429E+01    -1.285577E+01   -1.610021E+01     0.000000E+00   -1.610021E+01
                      CMX        0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                      CMY       -9.953998E+00   -9.953998E+00    -1.027399E+01   -1.249935E+01     0.000000E+00   -1.249935E+01
                      CMZ        0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00

     URDD3            CX         0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                      CY         0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                      CZ         0.000000E+00    0.000000E+00     3.634421E-03    0.000000E+00     3.333333E-02    0.000000E+00
                      CMX        0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                      CMY        0.000000E+00    0.000000E+00     2.623634E-03    0.000000E+00     7.272083E-03    0.000000E+00
                      CMZ        0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00

     URDD5            CX         0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                      CY         0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                      CZ         0.000000E+00    0.000000E+00     7.244891E-02    0.000000E+00     7.272083E-02    0.000000E+00
                      CMX        0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                      CMY        0.000000E+00    0.000000E+00     4.702158E-02    0.000000E+00     3.879043E-01    0.000000E+00
                      CMZ        0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00

     ELEV             CX         0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                      CY         0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                      CZ        -2.461394E-01   -2.461394E-01    -5.429842E-01   -5.219328E-01     0.000000E+00   -5.219328E-01
                      CMX        0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                      CMY        5.715301E-01    5.715301E-01     3.860486E-01    3.956233E-01     0.000000E+00    3.956233E-01
                      CMZ        0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00


0     HALF-SPAN MODEL, STATIC SYMMETRIC LOADING                                                    SUBCASE 2

         N O N - D I M E N S I O N A L    H I N G E    M O M E N T    D E R I V A T I V E    C O E F F I C I E N T S



                    CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
                                    MACH = 9.0000E-01                    Q = 1.2000E+03

         CONTROL SURFACE = ELEV         REFERENCE CHORD LENGTH =  1.000000E+00     REFERENCE AREA =  1.000000E+00

             TRIM VARIABLE              RIGID                         ELASTIC                            INERTIAL
                                                           RESTRAINED      UNRESTRAINED         RESTRAINED      UNRESTRAINED
             AT REFERENCE        -1.541222E-01            -2.050690E-01   -2.403068E-01        0.000000E+00     0.000000E+00
             ANGLEA               3.103143E+01            -3.631997E+00   -2.366273E+01        0.000000E+00     0.000000E+00
             PITCH               -6.124346E+02            -6.461632E+02   -6.941561E+02        0.000000E+00     0.000000E+00
             URDD3                0.000000E+00             5.942839E-02    0.000000E+00        0.000000E+00     0.000000E+00
             URDD5                0.000000E+00             9.297780E-01    0.000000E+00        0.000000E+00     0.000000E+00
             ELEV                 1.193384E+02             1.138659E+02    1.140252E+02        0.000000E+00     0.000000E+00
                                    A E R O S T A T I C   D A T A   R E C O V E R Y   O U T P U T   T A B L E S
                    CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
                                      MACH = 9.000000E-01                Q = 1.200000E+03
                    CHORD = 1.0000E+01           SPAN = 4.0000E+01           AREA = 2.0000E+02

         TRIM ALGORITHM USED: LINEAR TRIM SOLUTION WITHOUT REDUNDANT CONTROL SURFACES.
```

Listing 7-2 Output for FSW Airplane in Level Flight (Continued)

AEROELASTIC TRIM VARIABLES

ID	LABEL	TYPE	TRIM STATUS	VALUE OF UX	
	INTERCEPT	RIGID BODY	FIXED	1.000000E+00	
501	ANGLEA	RIGID BODY	FREE	1.373015E-03	RADIANS
502	PITCH	RIGID BODY	FIXED	0.000000E+00	NONDIMEN. RATE
503	URDD3	RIGID BODY	FIXED	-1.000000E+00	LOAD FACTOR
504	URDD5	RIGID BODY	FIXED	0.000000E+00	RAD/S/S PER G
505	ELEV	CONTROL SURFACE	FREE	1.932495E-02	RADIANS

AERODYNAMIC PRESSURES ON THE AERODYNAMIC ELEMENTS

GRID	LABEL	AERODYNAMIC PRES. COEFFICIENTS	AERODYNAMIC PRESSURES
1	LS	1.501611E-01	1.801933E+02
2	LS	2.755903E-02	3.307083E+01
3	LS	1.161090E-02	1.393308E+01
4	LS	9.609878E-03	1.153185E+01
5	LS	1.188870E-01	1.426644E+02
6	LS	1.982195E-02	2.378634E+01
7	LS	8.882723E-03	1.065927E+01
8	LS	8.497599E-03	1.019712E+01
9	LS	-3.733836E-02	-4.480603E+01
10	LS	-3.894558E-03	-4.673470E+00
11	LS	-8.759526E-04	-1.051143E+00
12	LS	-2.026473E-04	-2.431767E-01
13	LS	5.280284E-03	6.336341E+00
14	LS	-3.127619E-03	-3.753142E+00
15	LS	-5.930585E-04	-7.116702E-01
16	LS	-1.144530E-03	-1.373435E+00
17	LS	1.412652E-01	1.695183E+02
18	LS	1.531674E-02	1.838009E+01
19	LS	2.150885E-03	2.581062E+00
20	LS	-2.372342E-03	-2.846811E+00
21	LS	1.080868E-01	1.297041E+02
22	LS	3.453917E-02	4.144700E+01
23	LS	9.403750E-03	1.128450E+01
24	LS	2.046694E-03	2.456033E+00
25	LS	8.574632E-02	1.028956E+02
26	LS	3.670282E-02	4.404338E+01
27	LS	1.572066E-02	1.886479E+01
28	LS	5.050940E-03	6.061128E+00
29	LS	6.889285E-02	8.267142E+01
30	LS	3.221075E-02	3.865290E+01
31	LS	1.784603E-02	2.141523E+01
32	LS	7.484510E-03	8.981412E+00
33	LS	5.325399E-02	6.390479E+01
34	LS	2.543124E-02	3.051749E+01
35	LS	1.617978E-02	1.941573E+01
36	LS	8.442393E-03	1.013087E+01
37	LS	3.524246E-02	4.229095E+01
38	LS	1.649207E-02	1.979048E+01
39	LS	1.132641E-02	1.359169E+01
40	LS	7.072832E-03	8.487399E+00

Listing 7-2 Output for FSW Airplane in Level Flight (Continued)

```
 *** LABEL NOTATIONS:  LS = LIFTING SURFACE,   ZIB = Z INTERFERENCE BODY ELEMENT,  ZSB = Z SLENDER BODY ELEMENT,
                                               YIB = Y INTERFERENCE BODY ELEMENT,  YSB = Y SLENDER BODY ELEMENT.

                     A E R O S T A T I C   D A T A   R E C O V E R Y   O U T P U T   T A B L E S
              CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
                               MACH = 9.000000E-01                Q = 1.200000E+03
              CHORD = 1.0000E+01           SPAN = 4.0000E+01            AREA = 2.0000E+02

                                   AERODYNAMIC FORCES ON THE AERODYNAMIC ELEMENTS

GROUP  GRID ID  LABEL        T1                 T2                 T3                 R1                 R2                 R3
    1     1000    LS     0.000000E+00       0.000000E+00       1.126208E+03       0.000000E+00       7.038799E+02       0.000000E+00
    1     1001    LS     0.000000E+00       0.000000E+00       2.066927E+02       0.000000E+00       1.291829E+02       0.000000E+00
    1     1002    LS     0.000000E+00       0.000000E+00       8.708175E+01       0.000000E+00       5.442609E+01       0.000000E+00
    1     1003    LS     0.000000E+00       0.000000E+00       7.207408E+01       0.000000E+00       4.504630E+01       0.000000E+00
    1     1004    LS     0.000000E+00       0.000000E+00       8.916527E+02       0.000000E+00       5.572829E+02       0.000000E+00
    1     1005    LS     0.000000E+00       0.000000E+00       1.486646E+02       0.000000E+00       9.291541E+01       0.000000E+00
    1     1006    LS     0.000000E+00       0.000000E+00       6.662042E+01       0.000000E+00       4.163776E+01       0.000000E+00
    1     1007    LS     0.000000E+00       0.000000E+00       6.373199E+01       0.000000E+00       3.983250E+01       0.000000E+00
    1     1100    LS     0.000000E+00       0.000000E+00      -2.800377E+02       0.000000E+00      -1.750236E+02       0.000000E+00
    1     1101    LS     0.000000E+00       0.000000E+00      -2.920919E+01       0.000000E+00      -1.825574E+01       0.000000E+00
    1     1102    LS     0.000000E+00       0.000000E+00      -6.569645E+00       0.000000E+00      -4.106028E+00       0.000000E+00
    1     1103    LS     0.000000E+00       0.000000E+00      -1.519855E+00       0.000000E+00      -9.499091E-01       0.000000E+00
    1     1104    LS     0.000000E+00       0.000000E+00       3.960213E+01       0.000000E+00       2.475133E+01       0.000000E+00
    1     1105    LS     0.000000E+00       0.000000E+00      -2.345714E+01       0.000000E+00      -1.466071E+01       0.000000E+00
    1     1106    LS     0.000000E+00       0.000000E+00      -4.447938E+00       0.000000E+00      -2.779962E+00       0.000000E+00
    1     1107    LS     0.000000E+00       0.000000E+00      -8.583972E+00       0.000000E+00      -5.364982E+00       0.000000E+00
    1     1108    LS     0.000000E+00       0.000000E+00       1.059489E+03       0.000000E+00       6.621808E+02       0.000000E+00
    1     1109    LS     0.000000E+00       0.000000E+00       1.148756E+02       0.000000E+00       7.179723E+01       0.000000E+00
    1     1110    LS     0.000000E+00       0.000000E+00       1.613164E+01       0.000000E+00       1.008227E+01       0.000000E+00
    1     1111    LS     0.000000E+00       0.000000E+00      -1.779257E+01       0.000000E+00      -1.112035E+01       0.000000E+00
    1     1112    LS     0.000000E+00       0.000000E+00       8.106509E+02       0.000000E+00       5.066568E+02       0.000000E+00
    1     1113    LS     0.000000E+00       0.000000E+00       2.590438E+02       0.000000E+00       1.619024E+02       0.000000E+00
    1     1114    LS     0.000000E+00       0.000000E+00       7.052813E+01       0.000000E+00       4.408008E+01       0.000000E+00
    1     1115    LS     0.000000E+00       0.000000E+00       1.535020E+01       0.000000E+00       9.593877E+00       0.000000E+00
    1     1116    LS     0.000000E+00       0.000000E+00       6.430974E+02       0.000000E+00       4.019359E+02       0.000000E+00
    1     1117    LS     0.000000E+00       0.000000E+00       2.752711E+02       0.000000E+00       1.720445E+02       0.000000E+00
    1     1118    LS     0.000000E+00       0.000000E+00       1.179049E+02       0.000000E+00       7.369059E+01       0.000000E+00
    1     1119    LS     0.000000E+00       0.000000E+00       3.788205E+01       0.000000E+00       2.367628E+01       0.000000E+00
    1     1120    LS     0.000000E+00       0.000000E+00       5.166964E+02       0.000000E+00       3.229352E+02       0.000000E+00
    1     1121    LS     0.000000E+00       0.000000E+00       2.415806E+02       0.000000E+00       1.509879E+02       0.000000E+00
    1     1122    LS     0.000000E+00       0.000000E+00       1.338452E+02       0.000000E+00       8.365325E+01       0.000000E+00
    1     1123    LS     0.000000E+00       0.000000E+00       5.613383E+01       0.000000E+00       3.508364E+01       0.000000E+00
    1     1124    LS     0.000000E+00       0.000000E+00       3.994049E+02       0.000000E+00       2.496281E+02       0.000000E+00
    1     1125    LS     0.000000E+00       0.000000E+00       1.907343E+02       0.000000E+00       1.192089E+02       0.000000E+00
    1     1126    LS     0.000000E+00       0.000000E+00       1.213483E+02       0.000000E+00       7.584271E+01       0.000000E+00
    1     1127    LS     0.000000E+00       0.000000E+00       6.331794E+01       0.000000E+00       3.957372E+01       0.000000E+00
    1     1128    LS     0.000000E+00       0.000000E+00       2.643184E+02       0.000000E+00       1.651990E+02       0.000000E+00
    1     1129    LS     0.000000E+00       0.000000E+00       1.236905E+02       0.000000E+00       7.730656E+01       0.000000E+00
    1     1130    LS     0.000000E+00       0.000000E+00       8.494807E+01       0.000000E+00       5.309254E+01       0.000000E+00
    1     1131    LS     0.000000E+00       0.000000E+00       5.304624E+01       0.000000E+00       3.315390E+01       0.000000E+00
```

Listing 7-2 Output for FSW Airplane in Level Flight (Continued)

```
     *** LABEL NOTATIONS:  LS = LIFTING SURFACE,   ZSB =  Z SLENDER BODY ELEMENT,  YSB =  Y SLENDER BODY ELEMENT,
                                              ZYSB = ZY SLENDER BODY ELEMENT, EXTA = EXTERNAL AERO.

0     HALF-SPAN MODEL, STATIC SYMMETRIC LOADING                                                     SUBCASE 3

   N O N - D I M E N S I O N A L   S T A B I L I T Y   A N D   C O N T R O L   D E R I V A T I V E   C O E F F I C I E N T S

                     CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
                                     MACH = 1.3000E+00                    Q = 1.1510E+03
                     CHORD = 1.0000E+01           SPAN = 4.0000E+01           AREA = 2.0000E+02
            TRANSFORMATION FROM BASIC TO REFERENCE COORDINATES:

          { X }        [ -1.0000   0.0000   0.0000  ]  { X }         { 1.5000E+01 }
          { Y }    =   [  0.0000   1.0000   0.0000  ]  { Y }      +  { 0.0000E+00 }
          { Z }REF     [  0.0000   0.0000  -1.0000  ]  { Z }BAS      { 0.0000E+00 }

   CONTROLLER STATE: INTERCEPT ONLY, ALL CONTROLLERS ARE ZERO


   TRIM VARIABLE   COEFFICIENT             RIGID                          ELASTIC                          INERTIAL
                                  UNSPLINED        SPLINED       RESTRAINED      UNRESTRAINED      RESTRAINED      UNRESTRAINED

   REF. COEFF.      CX          0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                    CY          0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                    CZ         -7.352402E-03   -7.352402E-03    -7.171850E-03   -8.557491E-03     0.000000E+00   -8.557491E-03
                    CMX         0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                    CMY        -7.194684E-03   -7.194684E-03    -6.958842E-03   -8.269984E-03     0.000000E+00   -8.269984E-03
                    CMZ         0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00

   ANGLEA           CX          0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                    CY          0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                    CZ         -4.847309E+00   -4.847309E+00    -4.947807E+00   -5.783348E+00     0.000000E+00   -5.783348E+00
                    CMX         0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                    CMY        -3.884564E+00   -3.884564E+00    -3.932827E+00   -4.727888E+00     0.000000E+00   -4.727888E+00
                    CMZ         0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00

   PITCH            CX          0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                    CY          0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                    CZ         -9.055189E+00   -9.055189E+00    -7.611276E+00   -9.304676E+00     0.000000E+00   -9.304676E+00
                    CMX         0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                    CMY        -1.014906E+01   -1.014906E+01    -8.768779E+00   -1.036007E+01     0.000000E+00   -1.036007E+01
                    CMZ         0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00

   URDD3            CX          0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                    CY          0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                    CZ          0.000000E+00    0.000000E+00     2.447214E-03    0.000000E+00     3.475239E-02    0.000000E+00
                    CMX         0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                    CMY         0.000000E+00    0.000000E+00     2.469910E-03    0.000000E+00     7.581668E-03    0.000000E+00
                    CMZ         0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00

   URDD5            CX          0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                    CY          0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                    CZ          0.000000E+00    0.000000E+00     5.183135E-02    0.000000E+00     7.581668E-02    0.000000E+00
                    CMX         0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                    CMY         0.000000E+00    0.000000E+00     4.722255E-02    0.000000E+00     4.044180E-01    0.000000E+00
                    CMZ         0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
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Listing 7-2 Output for FSW Airplane in Level Flight (Continued)

```
ELEV            CX        0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                CY        0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                CZ       -6.346223E-01   -6.346223E-01    -8.385706E-01   -8.801843E-01     0.000000E+00   -8.801843E-01
                CMX       0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                CMY       2.377559E-01    2.377559E-01     5.436245E-02    1.054382E-02     0.000000E+00    1.054382E-02
                CMZ       0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00

                                                AEROELASTIC TRIM VARIABLES

                          ID     LABEL                 TYPE       TRIM STATUS      VALUE OF UX

                                 INTERCEPT          RIGID BODY           FIXED      1.000000E+00
                         501     ANGLEA             RIGID BODY            FREE     -5.119292E-05   RADIANS
                         502     PITCH              RIGID BODY           FIXED      0.000000E+00   NONDIMEN. RATE
                         503     URDD3              RIGID BODY           FIXED     -1.000000E+00   LOAD FACTOR
                         504     URDD5              RIGID BODY           FIXED      0.000000E+00   RAD/S/S PER G
                         505     ELEV           CONTROL SURFACE           FREE      3.027368E-02   RADIANS

                      A E R O S T A T I C   D A T A   R E C O V E R Y   O U T P U T   T A B L E S
                CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
                                  MACH = 1.300000E+00                Q = 1.151000E+03
                CHORD = 1.0000E+01           SPAN = 4.0000E+01            AREA = 2.0000E+02


                                          AERODYNAMIC PRESSURES ON THE AERODYNAMIC ELEMENTS

                                                   AERODYNAMIC PRES.       AERODYNAMIC
                                 GRID   LABEL          COEFFICIENTS           PRESSURES
                                   1     LS            1.390317E-01         1.600255E+02
                                   2     LS            1.039267E-01         1.196197E+02
                                   3     LS            4.975270E-02         5.726536E+01
                                   4     LS            1.373667E-02         1.581091E+01
                                   5     LS            1.171180E-01         1.348028E+02
                                   6     LS            6.698377E-02         7.709832E+01
                                   7     LS            4.058229E-02         4.671022E+01
                                   8     LS            1.227159E-02         1.412460E+01
                                   9     LS           -1.002813E-01        -1.154238E+02
                                  10     LS           -3.034249E-02        -3.492421E+01
                                  11     LS           -7.350946E-03        -8.460939E+00
                                  12     LS           -2.370119E-03        -2.728007E+00
                                  13     LS           -2.004911E-02        -2.307653E+01
                                  14     LS           -2.124941E-02        -2.445808E+01
                                  15     LS           -2.301381E-02        -2.648889E+01
                                  16     LS           -5.607886E-03        -6.454677E+00
                                  17     LS            1.605987E-01         1.848491E+02
                                  18     LS            3.754425E-02         4.321344E+01
                                  19     LS           -3.846656E-03        -4.427501E+00
                                  20     LS           -2.034214E-02        -2.341381E+01
                                  21     LS            7.659687E-02         8.816299E+01
                                  22     LS            7.658265E-02         8.814663E+01
                                  23     LS            3.448328E-02         3.969025E+01
                                  24     LS            2.927193E-03         3.369200E+00
                                  25     LS            4.240669E-02         4.881009E+01
                                  26     LS            4.723883E-02         5.437189E+01
                                  27     LS            5.111511E-02         5.883349E+01
                                  28     LS            3.402049E-02         3.915758E+01
                                  29     LS            2.497791E-02         2.874957E+01
```

Listing 7-2 Output for FSW Airplane in Level Flight (Continued)

```
                                         30      LS            2.738711E-02         3.152257E+01
                                         31      LS            3.429865E-02         3.947774E+01
                                         32      LS            3.888901E-02         4.476125E+01
                                         33      LS            1.786714E-02         2.056508E+01
                                         34      LS            1.355678E-02         1.560386E+01
                                         35      LS            1.867045E-02         2.148969E+01
                                         36      LS            2.563091E-02         2.950118E+01
                                         37      LS            1.257710E-02         1.447624E+01
                                         38      LS            7.189185E-03         8.274751E+00
                                         39      LS            6.744018E-03         7.762365E+00
                                         40      LS            1.182459E-02         1.361010E+01

          *** LABEL NOTATIONS:  LS = LIFTING SURFACE,   ZIB = Z INTERFERENCE BODY ELEMENT,  ZSB = Z SLENDER BODY ELEMENT,
                                                        YIB = Y INTERFERENCE BODY ELEMENT,  YSB = Y SLENDER BODY ELEMENT.
1     EXAMPLE HA144A: 30 DEG FWD SWEPT WING WITH CANARD HA14 HA144A            MARCH  25, 2019  MSC Nastran  3/25/19   PAGE    46
       SYMMETRIC FLIGHT CONDITIONS, DOUBLET-LATTICE AERO
0      HALF-SPAN MODEL, STATIC SYMMETRIC LOADING                                                                   SUBCASE 3

                             A E R O S T A T I C   D A T A   R E C O V E R Y   O U T P U T   T A B L E S
                       CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
                                        MACH = 1.300000E+00                Q = 1.151000E+03
                       CHORD = 1.0000E+01           SPAN = 4.0000E+01           AREA = 2.0000E+02


                                          AERODYNAMIC FORCES ON THE AERODYNAMIC ELEMENTS

    GROUP  GRID ID  LABEL        T1               T2               T3               R1               R2               R3
        1     1000    LS     0.000000E+00     0.000000E+00     1.000160E+03     0.000000E+00     0.000000E+00     0.000000E+00
        1     1001    LS     0.000000E+00     0.000000E+00     7.476228E+02     0.000000E+00     0.000000E+00     0.000000E+00
        1     1002    LS     0.000000E+00     0.000000E+00     3.579085E+02     0.000000E+00     0.000000E+00     0.000000E+00
        1     1003    LS     0.000000E+00     0.000000E+00     9.881820E+01     0.000000E+00     0.000000E+00     0.000000E+00
        1     1004    LS     0.000000E+00     0.000000E+00     8.425175E+02     0.000000E+00     0.000000E+00     0.000000E+00
        1     1005    LS     0.000000E+00     0.000000E+00     4.818645E+02     0.000000E+00     0.000000E+00     0.000000E+00
        1     1006    LS     0.000000E+00     0.000000E+00     2.919388E+02     0.000000E+00     0.000000E+00     0.000000E+00
        1     1007    LS     0.000000E+00     0.000000E+00     8.827874E+01     0.000000E+00     0.000000E+00     0.000000E+00
        1     1100    LS     0.000000E+00     0.000000E+00    -7.213988E+02     0.000000E+00     0.000000E+00     0.000000E+00
        1     1101    LS     0.000000E+00     0.000000E+00    -2.182763E+02     0.000000E+00     0.000000E+00     0.000000E+00
        1     1102    LS     0.000000E+00     0.000000E+00    -5.288087E+01     0.000000E+00     0.000000E+00     0.000000E+00
        1     1103    LS     0.000000E+00     0.000000E+00    -1.705004E+01     0.000000E+00     0.000000E+00     0.000000E+00
        1     1104    LS     0.000000E+00     0.000000E+00    -1.442283E+02     0.000000E+00     0.000000E+00     0.000000E+00
        1     1105    LS     0.000000E+00     0.000000E+00    -1.528630E+02     0.000000E+00     0.000000E+00     0.000000E+00
        1     1106    LS     0.000000E+00     0.000000E+00    -1.655556E+02     0.000000E+00     0.000000E+00     0.000000E+00
        1     1107    LS     0.000000E+00     0.000000E+00    -4.034173E+01     0.000000E+00     0.000000E+00     0.000000E+00
        1     1108    LS     0.000000E+00     0.000000E+00     1.155307E+03     0.000000E+00     0.000000E+00     0.000000E+00
        1     1109    LS     0.000000E+00     0.000000E+00     2.700840E+02     0.000000E+00     0.000000E+00     0.000000E+00
        1     1110    LS     0.000000E+00     0.000000E+00    -2.767188E+01     0.000000E+00     0.000000E+00     0.000000E+00
        1     1111    LS     0.000000E+00     0.000000E+00    -1.463363E+02     0.000000E+00     0.000000E+00     0.000000E+00
        1     1112    LS     0.000000E+00     0.000000E+00     5.510187E+02     0.000000E+00     0.000000E+00     0.000000E+00
        1     1113    LS     0.000000E+00     0.000000E+00     5.509165E+02     0.000000E+00     0.000000E+00     0.000000E+00
        1     1114    LS     0.000000E+00     0.000000E+00     2.480641E+02     0.000000E+00     0.000000E+00     0.000000E+00
        1     1115    LS     0.000000E+00     0.000000E+00     2.105750E+01     0.000000E+00     0.000000E+00     0.000000E+00
        1     1116    LS     0.000000E+00     0.000000E+00     3.050631E+02     0.000000E+00     0.000000E+00     0.000000E+00
        1     1117    LS     0.000000E+00     0.000000E+00     3.398243E+02     0.000000E+00     0.000000E+00     0.000000E+00
        1     1118    LS     0.000000E+00     0.000000E+00     3.677093E+02     0.000000E+00     0.000000E+00     0.000000E+00
        1     1119    LS     0.000000E+00     0.000000E+00     2.447349E+02     0.000000E+00     0.000000E+00     0.000000E+00
        1     1120    LS     0.000000E+00     0.000000E+00     1.796848E+02     0.000000E+00     0.000000E+00     0.000000E+00
        1     1121    LS     0.000000E+00     0.000000E+00     1.970160E+02     0.000000E+00     0.000000E+00     0.000000E+00
        1     1122    LS     0.000000E+00     0.000000E+00     2.467359E+02     0.000000E+00     0.000000E+00     0.000000E+00
```

Listing 7-2 Output for FSW Airplane in Level Flight (Continued)

```
1    1123   LS    0.000000E+00    0.000000E+00    2.797578E+02    0.000000E+00    0.000000E+00    0.000000E+00
1    1124   LS    0.000000E+00    0.000000E+00    1.285318E+02    0.000000E+00    0.000000E+00    0.000000E+00
1    1125   LS    0.000000E+00    0.000000E+00    9.752410E+01    0.000000E+00    0.000000E+00    0.000000E+00
1    1126   LS    0.000000E+00    0.000000E+00    1.343106E+02    0.000000E+00    0.000000E+00    0.000000E+00
1    1127   LS    0.000000E+00    0.000000E+00    1.843824E+02    0.000000E+00    0.000000E+00    0.000000E+00
1    1128   LS    0.000000E+00    0.000000E+00    9.047648E+01    0.000000E+00    0.000000E+00    0.000000E+00
1    1129   LS    0.000000E+00    0.000000E+00    5.171720E+01    0.000000E+00    0.000000E+00    0.000000E+00
1    1130   LS    0.000000E+00    0.000000E+00    4.851478E+01    0.000000E+00    0.000000E+00    0.000000E+00
1    1131   LS    0.000000E+00    0.000000E+00    8.506313E+01    0.000000E+00    0.000000E+00    0.000000E+00

  *** LABEL NOTATIONS:  LS = LIFTING SURFACE,   ZSB =  Z SLENDER BODY ELEMENT,  YSB =  Y SLENDER BODY ELEMENT,
                                            ZYSB = ZY SLENDER BODY ELEMENT, EXTA = EXTERNAL AERO.
```

CSV File Output

If the CSV file named HA144CSVT.CSV is opened into a spreadsheet application, such as Microsoft XL, it will be seen that the data consists of 4 rows (one for header information and three for results from the three subcases) and 43 columns. The data in the columns can be described as:

Table 7-3 Contents of HA144CSVT

Col(s)	Contents
1 (A)	Subcase ID
2 (B)	Mach Number
3 (C)	Dynamic Pressure
4-9 (D-I)	Trim Parameters
10-19 (J-S)	Mass and CG Data
20-25 (T-Y)	MONPNT1 results for WINGSTRC
26-31 (Z-AE)	MONPNT1 results for WINGSUM
32-39 (AF-AI)	MONPTNT2 results
40-43 (AJ-AO)	MONDSP1 results for RWTAD

If the CSV file named HA144CSVS.CSV is opened into a spreadsheet application, such as Microsoft XL, it will be seen that the data consists of 4 rows (one for header information and three for results from the three subcases) and 216 columns.

The data represent the triplets of six aerodynamic extra points, six types of derivative and six components. It is felt that this condensed representation of the results could be of value in a production environment where hundreds of subcases are analyzed simultaneously.

Selected Flightload Plots

As described in the MSC Flightloads section of this guide, MSC FlightLoads provides a user interface to MSC Nastran's aeroelastic capability and therefore provides powerful postprocessing tools for the static aeroelastic results. This section provides representative plots that can be produced for this Forward Swept Wing example. Documentation for this capability is provided in the MSC.Flightloads and Dynamics User's Guide.

Figure 7-2 is a contour plot of the rigid pressure distribution on the planform for the second subcase while Figure 7-3 is the same plot for the third supersonic subcase. These plots are for the trimmed results and it is noted in both cases that the majority of the positive pressure is on the canard and that the positive deflection of the canard results in negative pressures on the leading edge root of the wing. Figure 7-4 is a contour plot of the elastic incremental pressure distribution for the second subcase while Figure 7-5 is the same plot for the third subcase. There is very change on the canard while there is a positive increment in pressure across the entire wing due to the nature of the forward swept wing deforming in a way that represents a positive angle of attack.

A unique feature of FlightLoads relative to the underlying MSC Patran is its ability to generate running loads. Figure 7-6 depicts the rigid portion of the running shear loads across the span of the vehicle for the three subcases. Figure 7-7 shows the elastic increment for these three subcases. It is seen that there is negligible change for the first subcase, a subsonic, low q condition. In this case, the increment at the subsonic condition of subcase 2 is considerable larger than the supersonic increment of subcase 3.

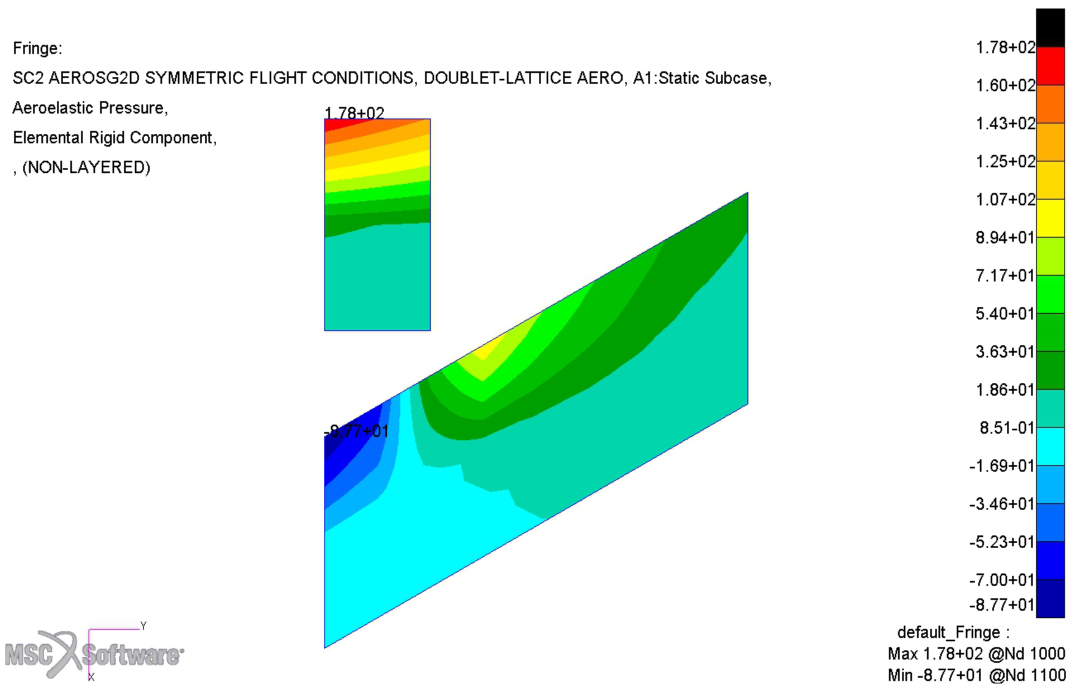

Figure 7-2 Subcase 2, Rigid Pressure Distribution Trimmed Flight at M=0.9

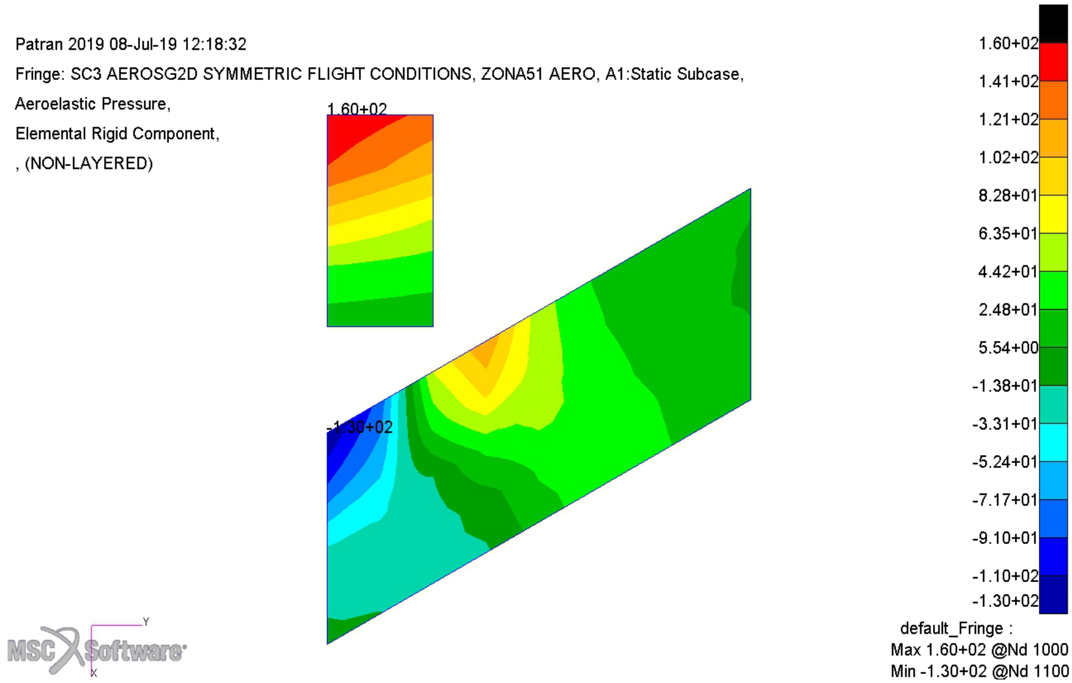

Figure 7-3 Subcase 3 Rigid Pressure Distribution Trimmed Flight at M=13

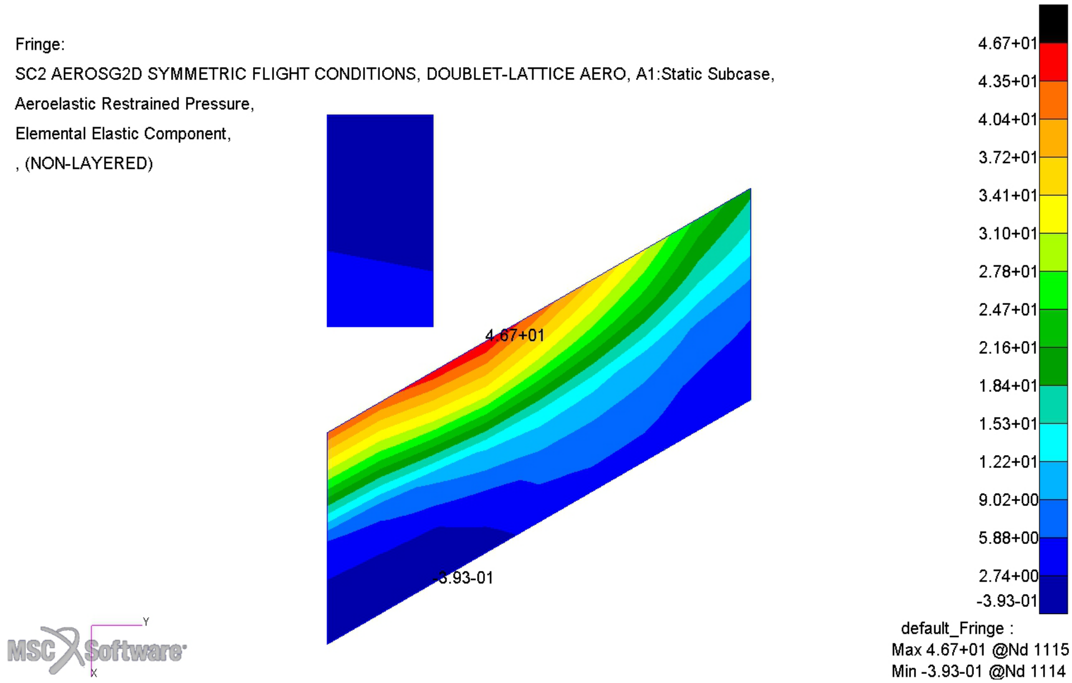

Figure 7-4 Subcase 2, Elastic Incremental Pressure Distribution for Trimmed Flight M=0.9

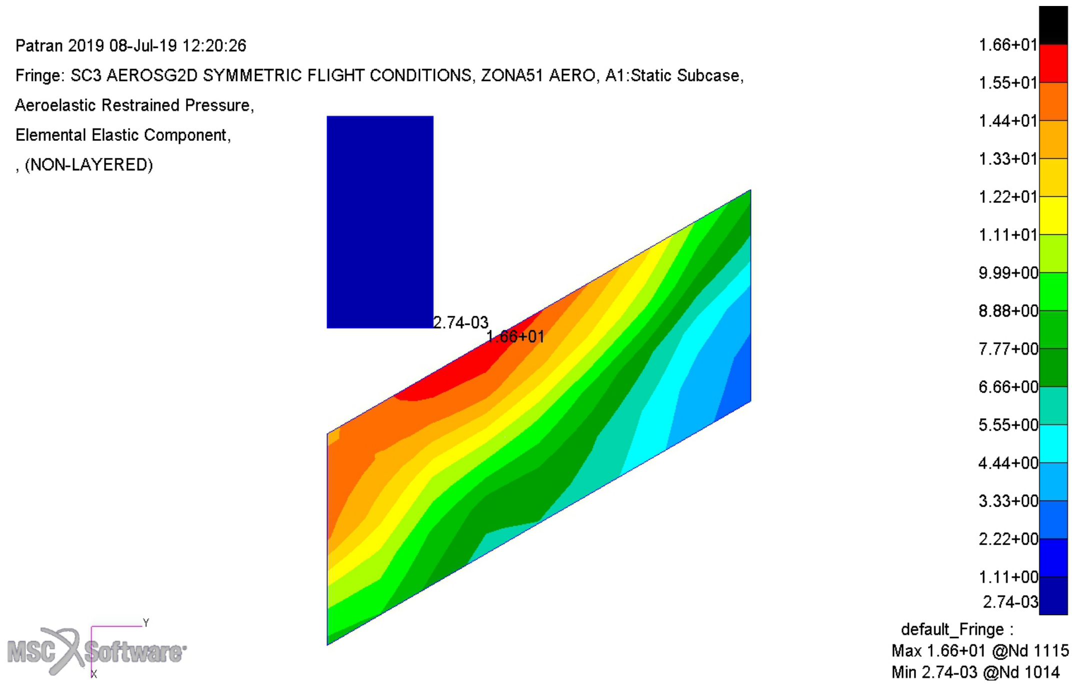

Figure 7-5 Subcase 3 Elastic Incremental Pressure Distribution in Trimmed Flight at M=13

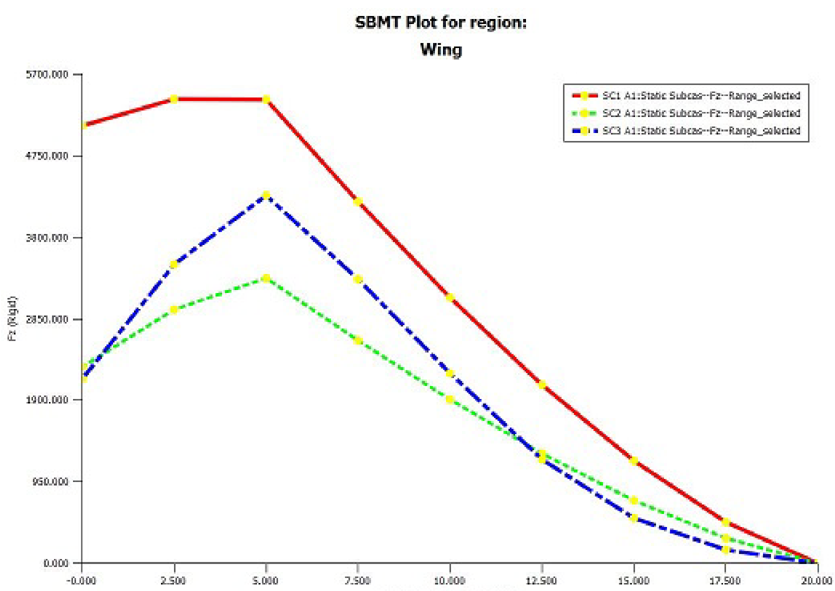

Figure 7-6 Rigid Shear Force along the Span of the Vehicle for Three Subcases

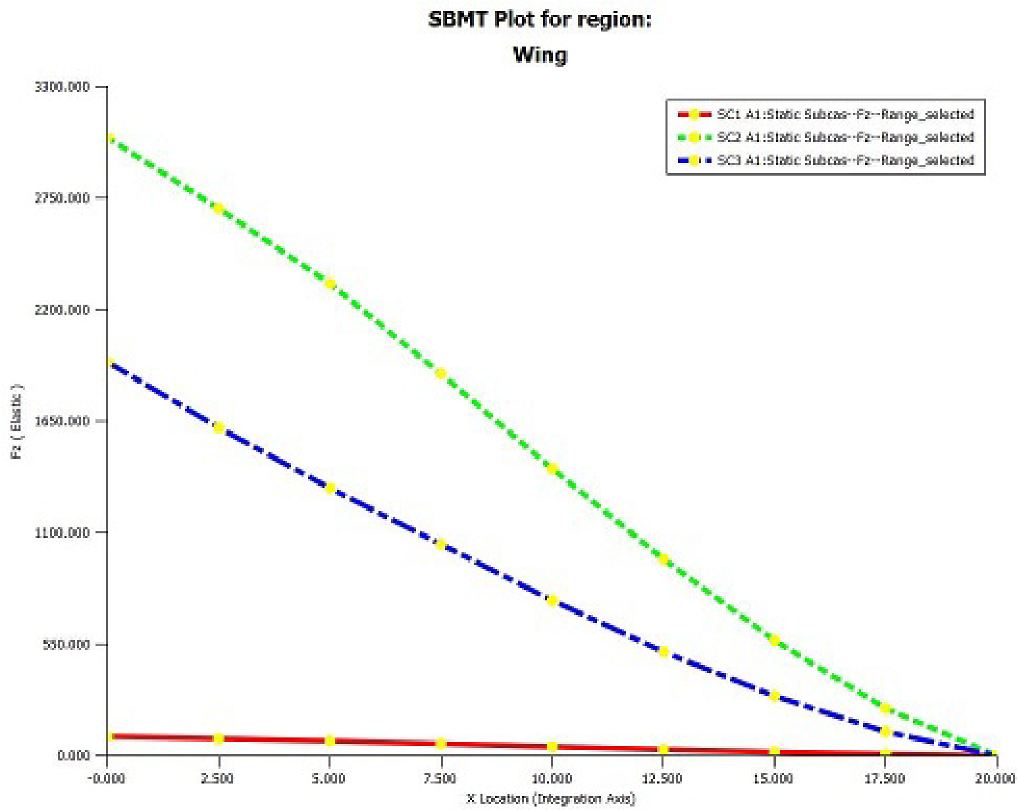

Figure 7-7 Elastic Incremental Shear Force along the Span of the Vehicle for Three Subcases

Jet Transport Wing in Roll

The BAH wing in steady roll is the jet transport wing considered throughout Bisplinghoff, Ashley, and Halfman (1955) [Reference 8] and adapted as an MSC Nastran demonstration problem by Rodden, Harder, and Bellinger (1979) [Reference 50]. The present idealization of the wing/aileron combination is shown in Figure 7-8. The figure shows a more refined aerodynamic box idealization than that used previously). The reference geometrical characteristics for the stability derivatives are the wing area, $S = 81{,}250 \text{ in}^2$ per side, the reference chord, $\bar{c} = 162.5 \text{ in.}$, and the total span, $b = 1000.0 \text{ in}$.

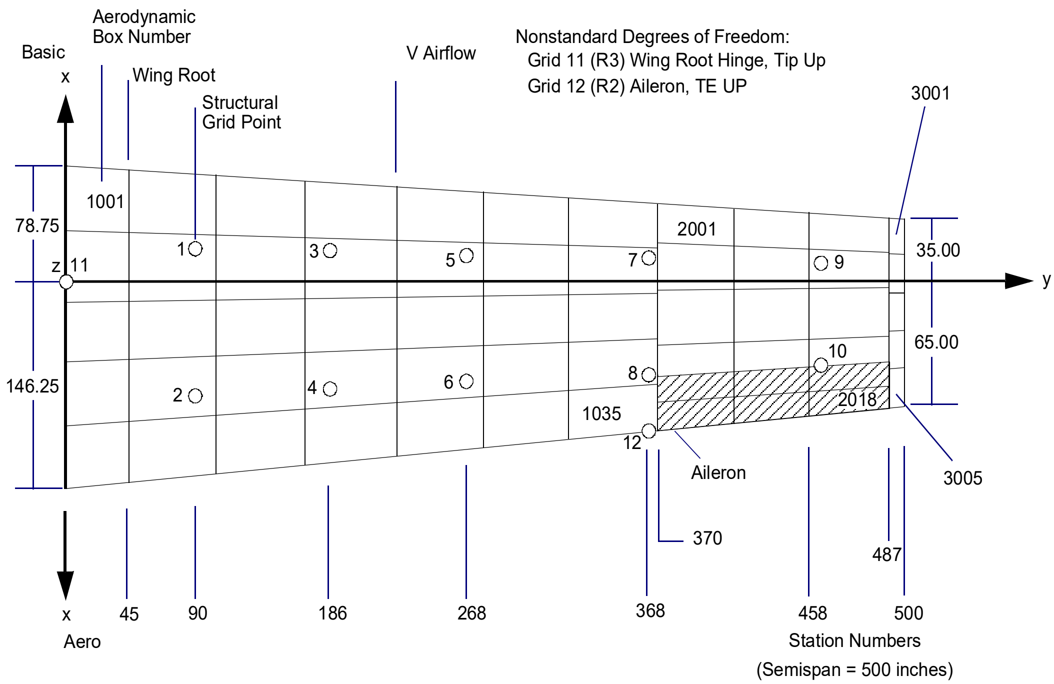

Figure 7-8 Idealization of BAH Wing for Rolling Analysis

The BAH wing flexibility influence coefficients and mass matrix are given by Rodden (1959a) [Reference 40] for the idealization of Figure 7-8. In addition to the data of Rodden (1959a) [Reference 40], the half-fuselage is assumed to have a weight of 17,400 lbs with pitch and roll moments of inertia of $4.35 \times 10^9 \text{ lb-in}^2$ and $4.37 \times 10^7 \text{ lb-in}^2$, respectively.

Bisplinghoff, Ashley, and Halfman (1955, pp. 176-184) [Reference 8] give the half-fuselage weight as 17,400 lbs and the half-airplane moment of inertia in roll as 135.02 lb-in^2. The moment of inertia in roll of the half-fuselage is derived to be 4.37×10^7 lb-in^2, and the moment of inertia in pitch is arbitrarily assumed to be 4.35×10^7 lb-in^2

The aileron actuator stiffness is derived from the data in Bisplinghoff, Ashley, and Halfman (1955, pp. 580-584) [Reference 8] to give an uncoupled rotational frequency of 60.0 Hz. The wing is idealized into 58 aerodynamic boxes, five of which are on the fuselage and six of which are on the aileron.

The wing is assumed to be flying in incompressible air (Mach number, $m = 0.0$) and at a dynamic pressure $\bar{q} = 4.0075$ psi for comparison to a Fourier transform solution by Rodden, Harder, and Bellinger (1979) [Reference 50].

The BAH wing is used in several examples throughout this guide. In the interest of saving space in the guide, certain groups of Bulk Data are contained in separate input files and are incorporated into the input data section by means of the INCLUDE entry. In this example the structural, mass, aileron, and aerodynamic planform data are separated as discussed in the following.

The structural stiffness data are input using GENEL entries since the structural model of the BAH wing is given only in terms of flexibility influence coefficients. The GRID entries list the wing grid points 1 through 10, which are the control points for the flexibility matrix, and GRID 11 represents the rigid fuselage at the root of the wing elastic axis. The GENEL partitions include the flexibility matrix Z and the rigid body mode matrix S for plunging, rolling about the centerline, pitching about the elastic axis, and flapping about the wing root. The structural stiffness data are contained in the input file BAH_STRUCT.DAT and are shown in Listing 7-3.

The wing inertial data are derived from the three masses on each wing strip given by Rodden (1959a) [Reference 40] and are input in the CMASS2 format, which provides for the inertial coupling between the forward (25% chord) and aft (75% chord) degrees of freedom. CONM1 is the concentrated rigid fuselage mass, static unbalance, and inertia. PARAM,GRDPNT specifies GRID 11 as the reference in the weight and balance analysis. PARAM,WTMASS = 1/g converts the input weights to units of mass. The inertial data are contained in the input file BAH_MASS.DAT and are shown in Listing 7-4.

The relative rotation between the aileron and the wing is represented by GRID 12. GRID 12 is located streamwise behind GRIDs 7 and 8 on the wing trailing edge slightly inboard of the aileron inboard edge. MPC 1 defines the control surface rotation relative to the wing based on the chord lengths between GRIDs 7 and 8 (66.50 in.) and between GRIDs 8 and 12 (33.25 in) at wing station 368. CONM1 2 gives the aileron inertial characteristics: weight (0.0 lbs), unbalance about the hinge line (0.0 in-lbs), and moment of inertia about the hinge line ($13,970.$lb-in^2). CELAS2 3 provides the rotational stiffness of the aileron actuator and is derived from the moment of inertia and the assumed uncoupled frequency of 60.0 Hz

$(13970.5/g) \cdot (2\pi \cdot 60.0)^2 = 5{,}142{,}661$ in-lb/rad. The aileron data are contained in the input file BAH_AILERON.DAT and are shown in Listing 7-5.

Aerodynamic Data

The definition of the wing geometry begins with CORD2R 1, which has its x-axis in the streamwise direction. The wing planform is divided into three panels via combinations of three CAERO1 entries and four AEFACT entries.

- The panel between the centerline and the aileron is specified by CAERO1 1001; by NCHORD = 5, which divides it into five equal chordwise boxes; and by AEFACT 1, which divides it into seven unequal spanwise strips.
- The panel containing the aileron is specified by CAERO1 2001 and is divided spanwise into three strips and chordwise into six boxes by AEFACTs 2 and 4, respectively.
- CAERO1 3001 specifies the wing tip with NCHORD = 5 and AEFACT 3. PAERO1 1000 is the required aerodynamic property entry although no body aerodynamics are considered in this example.

The fuselage aerodynamics are found from the extension of the wing between the centerline and the side of the fuselage.

Spline Data

Linear splines are used to connect the wing aerodynamics to the wing structure, consisting of grid points listed on SET1 14. SPLINE2 101 connects the first 35 boxes to the wing structure. Since the GENEL has no rotations, DTHX = DTHY = -1.0. SPLINE2 102 connects boxes 2001 through 2004, 2007 through 2010, and 2013 through 2016 to the wing structure (see Remark 1 on the SPLINE1 Bulk Data entry). SPLINE2 103 connects boxes 3001 through 3005 to the wing structure. The aerodynamic elements are specified in the input file BAH_AERO58.DAT as shown in Listing 7-6.

The requirements in the Bulk Data Section for the static aeroelastic analysis begin with the AESTAT entries that specify the antisymmetric trim parameters, roll rate, $pb/2V = \mathrm{ROLL}$, and rolling acceleration, $\dot{p} = \mathrm{URDD4}$. The aileron rotation δ_a is defined on AESURF as AILE using the hinge line coordinate system CORD2R 10 and by defining the aileron doublet-lattice boxes on AELIST 2005 that lists the six boxes: 2005, 2006, 2011, 2012, 2017 and 2018. SPLINE 104 specifies a plane through the aileron and connects the three SET 15 grid points to the six aileron boxes.

The geometry is given on AEROS that specifies CORD2R 1 as both the aerodynamic and rigid body motion reference coordinate systems, a reference chord of $\mathrm{REFC} = \bar{c} = 162.5\ \mathrm{in}$, a reference span of $\mathrm{REFB} = b = 1000.0\ \mathrm{in}$, a reference area of $\mathrm{REFS} = S = 81{,}250.0\ \mathrm{in}^2$, and antisymmetric aerodynamic motion (SYMXZ = -1). The TRIM entry specifies the flight condition at Mach number, $m = 0.0$, with a dynamic pressure, $Q = 4.00075\ \mathrm{psi}$ [corresponding to $V = 475\ \mathrm{mph}$ in Bisplinghoff, Ashley, and Halfman (1955) [Reference 8] and the units used in the present analysis], and a steady roll maneuver, $\dot{p} = \mathrm{URDD4} = 0.0$, with unit aileron rotation $\delta_a = \mathrm{AILE} = 1.0\ \mathrm{radian}$.

$\mathrm{PARAM,AUNITS} = 1/g = 0.0025907$ permits accelerations to be input in load factor units. ENDDATA completes the Bulk Data Section.

Case Control Commands

The Case Control Section begins with three title commands. ECHO = BOTH calls for both annotated and sorted input entries to be listed. SPC = 13 specifies the fuselage (GRID 11) to be constrained in plunge and pitch. MPC = 1 gives the relative angle between the control surface and the wing in terms of wing vertical displacements at GRIDs 7 and 8 and the trailing edge vertical displacement at GRID 12. DISP = 2 prints the displacements of SET 2, which includes GRIDs in the aileron region of the wing. SPCF = 3 prints the SPC forces on the SET 3 grid points, which is in this case the fuselage at GRID 11. AEROF = ALL and APRES = ALL call for all of the pressures and forces on the aerodynamic boxes to be printed. TRIM 1 specifies the maneuvering condition. BEGIN BULK ends the Case Control Section.

In the Executive Control Section, ID MSC, HA144B indicates this test problem identification. TIME 5 specifies the maximum CPU time at 5.0 minutes. SOL 144 calls for the static aeroelastic solution sequence. CEND concludes the Executive Control Section.

Output

The input data files are shown in Listing 7-7 followed by the sorted Bulk Data entries in Listing 7-8 and the output in Listing 7-9. The highlights of the computed results are discussed below.

The lateral stability derivatives are

$$C_l = C_{l_{\delta_a}}\delta_a + C_{l_p}\frac{pb}{2V} + C_{l_{\dot{p}}}\frac{\dot{p}b}{2g} \tag{7-3}$$

while the rotation of the lateral mean axis is given by

$$\gamma_m = \gamma_{m_{\delta_a}}\delta_a + \gamma_{m_p}\frac{pb}{2V} + \gamma_{m_{\dot{p}}}\frac{\dot{p}b}{2g} \tag{7-4}$$

In the unrestrained case, the inertial derivative vanishes, its effect is included in the other two derivatives, and the rotations are not needed in the rolling equation of motion.

At the Mach number $m = 0.0$, the restrained derivatives are found to be

$$C_{l_p} = -0.518943/\text{rad}$$

$$C_{l_{\dot{p}}} = -0.00021282/\text{rad}$$

$$C_{l_{\delta_a}} = 0.105493/\text{rad}$$

The output value for URDD4 is $C_{l_{\dot{p}}}\,b/2$; therefore, a division by $b/2 = 500$ in. leads to the value above.

The rotational derivatives are found from the intermediate matrix HP to be

$$\gamma_{m_p} = \frac{\partial\alpha_m}{\partial\left(\frac{pb}{2V}\right)} = 0.305455$$

$$\gamma_{m_{\dot{p}}} = \frac{\partial\alpha_p}{\partial\left(\frac{\dot{p}b}{2g}\right)} = 0.00419677$$

$$\gamma_{m_{\delta_a}} = \frac{\partial\alpha_p}{\partial\delta_a} = -0.0730480$$

where $\gamma_{m_{\dot{p}}}$ is obtained from the output by dividing by b/2. In the unrestrained case, the derivatives are

$$C_{l_p} = -0.505960/\mathrm{rad}$$

and

$$C_{l_{\delta_a}} = 0.102853/\mathrm{rad}$$

The trim solution gives a rolling helix angle of

$$pb/2V = -C_{l_{\delta_a}}\delta_a/C_{l_p} = 0.203284$$

for the aileron command of $\delta_a = 1.0\ \mathrm{rad}$. A dynamic response solution gives $pb/2V\delta_a = 0.197$ from its graphical solution (see Example HA146B (p. 667)).

The remaining output of interest gives the pressure coefficients, pressures, and aerodynamic box forces in the steady roll, and the deformations near the wing tip (GRIDs 7, 8, 9, and 10) and at the aileron trailing edge (GRID 12). The rotation of the aileron actuator spring is given by GRID12, R2 and is -0.05056 rad; this is the aeroelastic effect on the aileron, that is, the net commanded aileron rotation is only $1.0 - 0.05056 = 0.9435\ \mathrm{rad}$.

Structural element loads and stresses are not available in this example since the GENEL stiffness model does not contain any details of the structure.

The complete solution for aileron effectiveness as a function of dynamic pressure is shown in Figure 7-9. The aileron reversal dynamic pressure is found to be $\bar{q} = 11.06\ \mathrm{psi}$ by interpolation and corresponds to $V = 789\ \mathrm{mph}$ at sea level based on the incompressible aerodynamics assumed. Note that the curve in Figure 7-9 is not a straight line, although in this example its curvature is very small. Note also that the curve has not included the reduction in commanded aileron rotation due to the actuator flexibility.

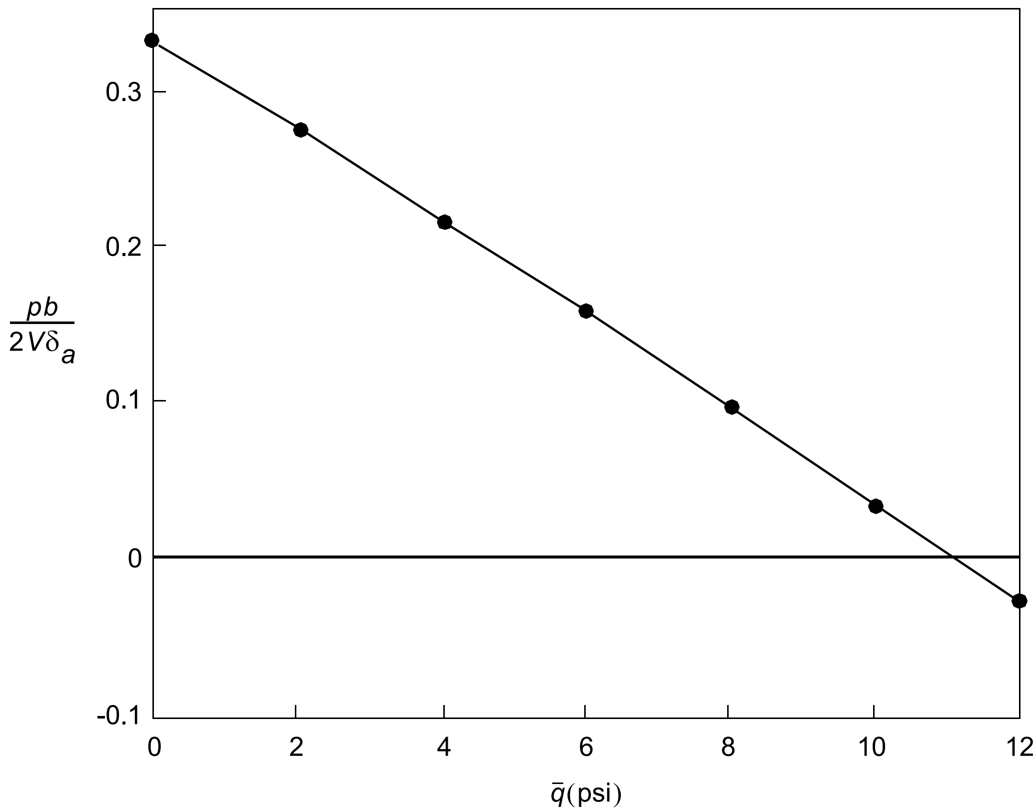

Figure 7-9 Aileron Effectiveness of BAH Wing

Listing 7-3 BAH_STRUCT.DAT Input File

```
$*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
$                                                                        $
$                    * * * STRUCTURAL DATA * * *                         $
$                                                                        $
$                        (LB-IN-SEC SYSTEM)                              $
$                                                                        $
$                     * * GRID GEOMETRY * *                              $
$                                                                        $
$        GRID 1 - 10  (T3)  WING CONTROL POINTS                          $
$        GRID     11  (T3,R1,R2)  BODY                                   $
$                     (R3)  WING ROOT HINGE                              $
$        GRID     12  (T3)  AILERON TRAILING EDGE CONTROL POINT          $
$                     (R2)  AILERON RELATIVE ROTATION                    $
$                                                                        $
$                                                                        $
$        THE GRID ENTRY DEFINES THE LOCATION OF A STRUCTURAL GRID        $
$        POINT.  LISTED ARE ITS COORDINATE SYSTEM ID, ITS LOCATION,      $
$        THE ID OF THE COORDINATE SYSTEM IN WHICH ITS DISPLACEMENTS      $
$        ARE DEFINED, ITS PERMANENT SINGLE-POINT CONSTRAINTS, AND        $
$        ITS ASSOCIATED SUPERELEMENT ID.                                 $
$                                                                        $
$        THE BAH JET TRANSPORT WING, AS SHOWN ON P.45 OF THE BOOK        $
$        "AEROELASTICITY" BY BISPLINGHOFF, ASHLEY AND HALFMAN, IS        $
$        ROTATED 180 DEG AROUND THE Y AXIS.  THAT ORIENTATION IS         $
$        RETAINED HERE.  POINTS 1 THRU 10 ARE ALONG THE ONE- AND         $
$        THREE-QUARTER CHORD LINES, POINT 11 IS AT THE ROOT OF THE       $
$        ELASTIC AXIS (35% CHORD),                                       $
$                                  .                                     $
$                                                                        $
$       ID      CP      X1      X2      X3      CD      PS      SEID
GRID    1                20.25  90.                     12456
GRID    2               -81.    90.                     12456
GRID    3                17.85  186.                    12456
GRID    4               -71.4   186.                    12456
GRID    5                15.8   268.                    12456
GRID    6               -63.2   268.                    12456
GRID    7                13.3   368.                    12456
GRID    8               -53.2   368.                    12456
GRID    9                11.05  458.                    12456
GRID    10              -44.2   458.                    12456
GRID    11                0.0     0.                    126
$                                                                        $
$                * * STRUCTURAL STIFFNESS PROPERTIES * *                 $
$                                                                        $
$                 * FLEXIBILITY INFLUENCE COEFFICIENTS *                 $
$                                                                        $
$        THE GENEL ENTRY DEFINES A GENERAL ELEMENT IN TERMS OF ITS       $
$        STRUCTURAL INFLUENCE COEFFICIENTS.  IT LISTS THE ELEMENT        $
$        ID NO. AND PAIRS OF GRID POINT NUMBERS PLUS THEIR UNCON-        $
$        STRAINED DOFS.  THIS IS FOLLOWED BY THE CORRESPONDING PAIRS     $
$        THAT WERE CONSTRAINED TO OBTAIN THE INFLUENCE COEFFICIENTS.     $
$        THIS IS FOLLOWED BY THE LOWER TRIANGULAR PART OF THE MATRIX     $
$        OF INFLUENCE COEFFICIENTS.  FINALLY, A MATRIX OF GEOMETRIC      $
$        CONSTANTS IS LISTED.  THESE CONSTANTS PRODUCE TOTAL FORCES      $
$        AND MOMENTS DUE TO DEFLECTIONS IN EACH MODE, IN THIS CASE       $
$        LIFT, ROLLING MOMENT, PITCHING MOMENT AND WING ROOT BENDING     $
$        MOMENT.                                                         $
$                                                                        $
$       EID             UI1     CI1     UI2     CI2     UI3     CI3
GENEL   432             1       3       2       3       3       3       +01
$       UI4     CI4     UI5     CI5     UI6     CI6     UI7     CI7
+01     4       3       5       3       6       3       7       3       +02
$       UI8     CI8     UI9     CI9     UI10    CI10
+02     8       3       9       3       10      3                       +03
$      "UD"             UD1     CD1     UD2     CD2     UD3     CD3
+03     UD             11      3       11      4       11      5        +04
$       UD4     CD4
+04     11      6                                                       +05
$    "K"|"Z"    Z11     Z21     Z31     ETC      (BY COLUMNS)
+05     Z       8.7172-61.3361-61.2778-56.2720-61.6251-51.0492-52.0478-5+06
+06    1.5630-52.4285-52.0403-53.0861-56.2720-63.2297-51.0492-53.3529-5 +07
+07    1.5630-53.5021-52.0257-53.5785-52.7732-51.5726-54.8255-53.7628-5 +08
+08    7.3284-56.4338-59.5810-58.8378-56.3749-53.7628-58.0136-56.4338-5 +09
+09    1.0012-48.8378-51.1811-41.2758-41.1344-41.9350-41.8160-42.5283-4 +10
+10    2.4294-41.6999-41.8160-42.2920-42.4294-42.8249-43.6862-43.5052-4 +11
+11    5.2675-45.1171-44.2292-45.1171-45.7187-48.4840-48.2340-49.2340-4 +12
$      "S"     S11     S12     S13     ETC      (BY ROWS)
+12     S      1.0      90.0   -20.25    45.0    1.0     90.0    81.0    +13
+13    45.0    1.0     186.0   -17.85   141.0    1.0    186.0    71.4    +14
+14   141.0    1.0     268.0   -15.80   223.0    1.0    268.0    63.2    +15
+15   223.0    1.0     368.0   -13.30   323.0    1.0    368.0    53.2    +16
+16   323.0    1.0     458.0   -11.05   413.0    1.0    458.0    44.2    +17
+17   413.0
$                                                                        $
```

Listing 7-4 BAH_MASS.DAT Input File

```
$                                                                         $
$                 * * MASS AND INERTIA PROPERTIES * *                     $
$                                                                         $
$                           * WING MASSES *                               $
$                                                                         $
$        THE CMASS2 ENTRY DEFINES A SCALAR MASS ELEMENT WITHOUT           $
$        REFERENCE TO A PROPERTY ENTRY.  IT LISTS THE MASS, THE           $
$        GRID NO. AND ITS DOF COMPONENTS.  WHEN TWO GRID POINTS           $
$        ARE LISTED THE MASS IS ADDED TO BOTH POINTS.                     $
$                                                                         $
$       EID     M       G1      C1      G2      C2
CMASS2  121     5248.7  1       3
CMASS2  122     134.9   1       3       2       3
CMASS2  123     790.3   2       3
CMASS2  341     9727.   3       3
CMASS2  342     11005.  3       3       4       3
CMASS2  343     473.    4       3
CMASS2  561     3253.6  5       3
CMASS2  562     -139.7  5       3       6       3
CMASS2  563     946.3   6       3
CMASS2  781     2617.8  7       3
CMASS2  782     21.     7       3       8       3
CMASS2  783     782.3   8       3
CMASS2  9101    494.8   9       3
CMASS2  9102    -7.3    9       3       10      3
CMASS2  9103    185.2   10      3
$                                                                         $
$                  * FUSELAGE MASS AND INERTIA VALUES *                   $
$                                                                         $
$        THE CONM1 ENTRY DEFINES A 6 BY 6 SYMMETRIC INERTIA MATRIX        $
$        FOR A GRID POINT.  LISTED IS THE ID, THE GRID POINT NO.,         $
$        THE COORDINATE SYSTEM IN WHICH THE INERTIA MATRIX IS             $
$        DEFINED AND THE LOWER LEFT TRIANGULAR PART OF THE MATRIX.        $
$                                                                         $
$       EID     G       CID     M11     M21     M22     M31     M32
CONM1   1      11                                                       +51
$       M33     M41     M42     M43     M44     M51     M52     M53
+51     17400.                          4.37+7                          +52
$       M54     M55     M61     M62     M63     M64     M65     M66
+52            4.35+09
$                                                                         $
$                     * * STRUCTURAL PARAMETERS * *                       $
$                                                                         $
$        THE PARAM,WTMASS,GINV CAUSES ALL THE STRUCTURAL MASSES AND       $
$        MASS DENSITIES TO BE MULTIPLIED BY GINV (that is, BY ONE OVER       $
$        THE ACCELERATION OF GRAVITY).  THE DYNAMIC PRESSURE SUPPLIED     $
$        FOR AERODYNAMIC FORCE CALCULATIONS WILL NOT BE MULTIPLIED        $
$        BY GINV.                                                         $
$                                                                         $
PARAM   WTMASS  .0025907
$                                                                         $
$        THE PARAM,GRDPNT,XX ENTRY CAUSES THE GRID POINT WEIGHT           $
$        GENERATOR TO BE EXECUTED USING GRID POINT XX AS THE REF-         $
$        ERENCE POINT.  THEN THE INERTIA MATRIX, THE TRANSFER MATRIX      $
$        FROM BASIC TO PRINCIPAL AXES AND OTHER PERTINENT INERTIA         $
$        DATA ARE PRINTED.                                                $
$                                                                         $
PARAM   GRDPNT  11
$                                                                         $
```

Listing 7-5 BAH_AILERON.DAT Input File

```
$       GRID 12 IS INBOARD OF THE AILERON AND ON THE TRAILING EDGE;
$       IT IS ALIGNED STREAMWISE BEHIND GRIDS 7 AND 8 AND PROVIDES
$       THE MEANS TO INCLUDE THE AILERON IN THE ANALYSIS.
$
$       ID      CP      X1      X2      X3      CD      PS      SEID
GRID    12             -86.45  368.                     1246
$                                                                       $
$        THE CELAS2 ENTRY DEFINES A SCALAR SPRING ELEMENT WITHOUT       $
$        REFERENCE TO A PROPERTY ENTRY, IN THIS CASE AN AILERON         $
$        HINGE SPRING STIFFNESS.  IT LISTS THE ID, THE STIFFNESS,       $
$        THE CONNECTION POINT AND DOF COMPONENT.                        $
$                                                                       $
$       EID     K       G1      C1
CELAS2  3      5142661.12       5
$                                                                       $
$                 * * AILERON INERTIAL PROPERTIES * *                   $
$
CONM1   2       12                                                      +AIL1
+AIL1   0.0                                              0.0            +AIL2
+AIL2          13970.5
$
$        THE MPC ENTRY DEFINES A MULTIPOINT CONSTRAINT IN THE FORM      $
$        OF A LINEAR EQUATION.  IT LISTS A SET OF TRIPLES CONSISTING    $
$        OF THE GRID NO., THE CONSTRAINED DOF COMPONENTS AND THE        $
$        LINEAR COEFFICIENT.                                            $
$                                                                       $
$        THIS ONE SPECIFIES THAT THE Z DISPLACEMENT AT THE TRAILING     $
$        EDGE OF THE AILERON IS A LINEAR EXTRAPOLATION FROM POINTS      $
$        7 AND 8 PLUS THE DISTANCE FROM THE HINGE-LINE TO THE           $
$        TRAILING EDGE TIMES A UNIT (SMALL), ANGULAR ROTATION OF THE    $
$        AILERON.  SEE P.3.5-9 OF THE "HANDBOOK FOR DYNAMIC ANALYSIS"   $
$        FOR A DISCUSSION OF THE LAGRANGE MULTIPLIER METHOD WHICH       $
$        IS USED HERE TO INTRODUCE THE AILERON ROTATION DOF.            $
$                                                                       $
$       SID     G       C       A       G       C       A
MPC     1       12      3       -1.0    8       3       1.5             +MPC1
$               G       C       A       G       C       A
+MPC1   7      3      -0.5     12       5       33.25
```

Listing 7-6 BAH_AERO58.DAT Input File

```
$         THIS CORD2R ENTRY DEFINES THE AERO COORDINATE SYSTEM          $
$         FLAGGED BY THE AEROS ENTRY.  THE ORIGIN IS AT THE ROOT        $
$         OF THE ELASTIC AXIS.  LISTED ARE THE ORIGIN, A POINT          $
$         ALONG THE Z AXIS AND A POINT IN THE X-Z PLANE, ALL IN         $
$         THE RID COORDINATE SYSTEM.                                    $
$                                                                       $
$       CID     RID     A1      A2      A3      B1      B2      B3
CORD2R  1               0.      0.      0.      0.      .0      -1.     +C1
$       C1      C2      C3
+C1     -1.     0.      0.
$                                                                       $
$                                                                       $
$         THE CAERO1 ENTRY IS USED FOR DOUBLET-LATTICE AERODYNAMICS.    $
$         LISTED ARE ITS PAERO ENTRY ID AND THE COORDINATE SYSTEM       $
$         FOR LOCATING THE INBOARD AND OUTBOARD LEADING EDGE POINTS     $
$         (1 AND 4).  NSPAN AND NCHORD, OR LSPAN AND LCHORD, ARE        $
$         USED TO PARTITION THE WING INTO AERODYNAMIC PANELS,           $
$         THE FORMER FOR UNIFORMLY SPACED PANELS AND THE LATTER         $
$         FOR NON-UNIFORMLY SPACED PANELS.  IGID IS THE ID OF ITS       $
$         ASSOCIATED INTERFERENCE GROUP.  THE CONTINUATION ENTRY        $
$         DEFINES POINTS 1 AND 4, THE ROOT CHORD AND TIP CHORD.         $
$         THE BOXES FORMED BY THE GRID LINES WILL BE NUMBERED           $
$         BEGINNING WITH EID SO CHOOSE A NUMBER THAT IS UNIQUE,         $
$         AND IS GREATER THAN ALL STRUCTURAL GRID, SCALAR AND           $
$         EXTRA POINT IDS.                                              $
$                                                                       $
$       EID    PID    CP      NSPAN   NCHORD   LSPAN   LCHORD   IGID
CAERO1  1001   1000   0               5        1                1       +CA1
$      ( FWD LEFT POINT  )   ROOTCHORD ( FWD RIGHT POINT  )  TIP CHORD
+CA1    78.75  0.     0.      225.    35.      500.    0.       100.
$
CAERO1  2001   1000   0                        2       4        1       +CA2
+CA2    78.75  0.     0.      225.    35.     500.     0.       100.
$
CAERO1  3001   1000   0               5        3                1       +CA3
+CA3    78.75  0.     0.      225.    35.     500.     0.       100.
$                                                                       $
$         THE AEFACT ENTRY IS A UTILITY ENTRY USED TO SPECIFY LISTS OF   $
$         NUMBERS.  IN THIS EXAMLPLE THEY ARE IDENTIFIED BY THE ABOVE   $
$         CAERO1 ENTRIES.  THE FIRST ENTRY DEFINES THE SPANWISE DIVISIONS $
$         INBOARD OF THE AILERON.                                       $
$                                                                       $
$         THE SECOND ONE DEFINES THE SPANWISE DIVISIONS ACROSS THE      $
$         AILERON.                                                      $
$                                                                       $
$         THE THIRD ONE DEFINES THE SPANWISE DIVISIONS OF THE TIP       $
$         FAIRING.                                                      $
$                                                                       $
$         THE FOURTH ONE DEFINES THE CHORDWISE DIVISIONS OF THE         $
$         AILERON. THE AILERON HINGE-LINE IS AT THE THREE-QUARTER       $
$         CHORD LINE SO THERE ARE TWO CHORDWISE BOXES ON THE            $
$         AILERON.                                                      $
$                                                                       $
$       SID    D1     D2         D3    D4       D5       D6     D7
AEFACT  1      0.    .09         .21   .33      .45      .56    .66     +AE1
$       D8
+AE1   .74
$                                                                       $
AEFACT  2     .74    .82         .90   .974
$                                                                       $
AEFACT  3   .974     1.00
$                                                                       $
AEFACT  4   0.      .1875      .375   .625    .750    .875     1.00
$                                                                       $
$                                                                       $
$         THE PAERO1 ENTRY IS REQUIRED EVEN THOUGH IT IS NON-FUNCTIONAL $
$         (BECAUSE THERE ARE NO ASSOCIATED BODIES IN THIS EXAMPLE).     $
$                                                                       $
$       PID    B1     B2      B3    B4      B5    B6
PAERO1  1000
$                                                                       $
```

Listing 7-6 BAH_AERO58.DAT Input File (Continued)

```
$               * * SPLINE FIT ON THE LIFTING SURFACES * *               $
$                                                                        $
$                   * BEAM SPLINE FIT ON THE WING *                      $
$                                                                        $
$        THE SPLINE2 ENTRY SPECIFIES A BEAM SPLINE FOR INTERPOLAT-       $
$        ION OVER THE REGION OF THE CAERO ENTRY (ID1 AND ID2 ARE         $
$        THE FIRST AND LAST BOXES IN THIS REGION).  SETG REFERS          $
$        TO A SET1 ENTRY WHERE THE STRUCTURAL GRID POINTS ARE            $
$        DEFINED.  DZ AND DTOR ARE SMOOTHING CONSTANTS FOR LINEAR        $
$        ATTACHMENT AND TORSIONAL FLEXIBILITIES.  CID IDENTIFIES         $
$        THE CORD2R ENTRY THAT DEFINES THE SPLINE AXIS.  DHTX AND        $
$        DTHY ARE ROTATIONAL ATTACHMENT FLEXIBILITIES (-1.0 SPECI-       $
$        FIES NO ATTACHMENTS).                                           $
$                                                                        $
$       EID     CAERO   ID1     ID2     SETG    DZ      DTOR    CID
SPLINE2 101     1001    1001    1035    14      0.      1.      0       +SP1
$       DTHX    DTHY
+SP1    -1.0    -1.0
$
SPLINE2 102     2001    2001    2016    14      0.      1.      0       +SP2
+SP2    -1.0    -1.
$
SPLINE2 103     3001    3001    3005    14      0.      1.      0       +SP3
$                                                                        $
$                                                                        $
          THE SET1 ENTRY DEFINES THE SETS OF POINTS TO BE USED BY        $
          THE SURFACE SPLINE FOR INTERPOLATION.                          $
$                                                                        $
        SID     G1      G2      G3      G4      G5      G6
SET1    14      1      THRU     11
$                                                                        $
```

Listing 7-7 Input Files for Jet Transport Wing in Roll

```
   N A S T R A N   E X E C U T I V E   C O N T R O L   D E C K   E C H O


ID MSC, HA144B
$$$$$$$$  HANDBOOK FOR AEROELASTIC ANALYSIS EXAMPLE HA144B      $$$$$$$$
$                                                                      $
$       MODEL DESCRIPTION       BAH JET TRANSPORT WING EXAMPLE         $
$                               CANTILEVERED WING WITH TEN BEAM        $
$                               ELEMENTS AND DUMBBELL MASSES           $
$                                                                      $
$       SOLUTION                STATIC AEROELASTIC SOLUTION TO         $
$                               AN AILERON DEFLECTION USING DOUBLET    $
$                               LATTICE METHOD AERODYNAMICS AT MACH    $
$                               NO. 0.0                                $
$                                                                      $
$       OUTPUT                  PLOTS OF THE STICK MODEL AND AERO      $
$                               GRID, LISTS OF RESTRAINED AND          $
$                               UNRESTRAINED ANTISYMMETRIC STATIC      $
$                               STABILITY DERIVATIVES PLUS THE         $
$                               STRESSES AND DEFLECTIONS FOR A         $
$                               TYPICAL DESIGN CONDITION               $
$                                                                      $
$$$$$$$$                                                        $$$$$$$$
TIME  5 $ CPU TIME IN MINUTES
SOL 144 $ STATIC AERO
CEND


EXAMPLE HA144B: BAH JET TRANSPORT WING DYNAMIC ANALYSIS                          PAGE     2
 ANTISYMMETRIC,  58 BOXES, DOUBLET-LATTICE AERO
 AILERON ROLL, STATIC AERO SOLUTION
                                        C A S E   C O N T R O L   D E C K   E C H O
            CARD
            COUNT
              1      TITLE = EXAMPLE HA144B: BAH JET TRANSPORT WING DYNAMIC ANALYSIS
              2      SUBTI = ANTISYMMETRIC,  58 BOXES, DOUBLET-LATTICE AERO
              3      LABEL = AILERON ROLL, STATIC AERO SOLUTION
              4        ECHO  = BOTH
              5        SPC   = 13 $ ANTISYMMETRIC CONSTRAINTS
              6        MPC   =  1 $ CONTROL SURFACE RELATIVE MOTION
              7      $OUTPUT
              8        SET 2 = 7 THRU 12
              9        SET 3 = 11
             10        DISP  = 2
             11        SPCF  = 3
             12        AEROF = ALL
             13        APRES = ALL
             14        TRIM = 1
             15      BEGIN BULK
```

Listing 7-7 Input Files for Jet Transport Wing in Roll (Continued)

```
EXAMPLE HA144B: BAH JET TRANSPORT WING DYNAMIC ANALYSIS                                                          PAGE     3
 ANTISYMMETRIC,  58 BOXES, DOUBLET-LATTICE AERO
 AILERON ROLL, STATIC AERO SOLUTION
                                       I N P U T   B U L K   D A T A   D E C K   E C H O

                         .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                         $*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
                         $                                                                        $
                         $        THE ANNOTATIONS IN THIS INPUT SECTION ARE INTENDED TO           $
                         $        EXPLAIN THE DATA ON THE CARD IMAGES FOR THIS SPECIFIC           $
                         $        EXAMPLE WITHOUT REFERENCE TO THE VARIOUS MANUALS WHERE          $
                         $        MORE GENERAL DESCRIPTIONS WILL BE FOUND.                        $
                         $                                                                        $
                         $*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
                         $        THE GRID ENTRY DEFINES THE LOCATION OF A STRUCTURAL GRID        $
                         $        POINT.  LISTED ARE ITS COORDINATE SYSTEM ID, ITS LOCATION,      $
                         $        THE ID OF THE COORDINATE SYSTEM IN WHICH ITS DISPLACEMENTS      $
                         $        ARE DEFINED, ITS PERMANENT SINGLE-POINT CONSTRAINTS, AND        $
                         $        ITS ASSOCIATED SUPERELEMENT ID.                                 $
                         $                                                                        $
                         $        THE BAH JET TRANSPORT WING, AS SHOWN ON P.45 OF THE BOOK        $
                         $        "AEROELASTICITY" BY BISPLINGHOFF, ASHLEY AND HALFMAN, IS        $
                         $        ROTATED 180 DEG AROUND THE Y AXIS.  THAT ORIENTATION IS         $
                         $        RETAINED HERE.  POINTS 1 THRU 10 ARE ALONG THE ONE- AND         $
                         $        THREE-QUARTER CHORD LINES, POINT 11 IS AT THE ROOT OF THE       $
                         $        ELASTIC AXIS (35% CHORD), AND POINT 12 IS AT THE INBOARD        $
                         $        TRAILING EDGE OF THE AILERON.                                   $
                         $                                                                        $
                         INCLUDE BAH_STRUCT.DAT
                         $
                         INCLUDE BAH_MASS.DAT
                         $
                         INCLUDE BAH_AILERON.DAT
                         $                                                                        $
                         $                      * * STRUCTURAL CONSTRAINTS * *                    $
                         $                                                                        $
                         $        THE SPC ENTRY DEFINES SETS OF SINGLE-POINT CONSTRAINTS          $
                         $        AND ENFORCED DISPLACEMENTS.  IT LISTS THE ID, GRID POINT        $
                         $        NO., CONSTRAINED DOFS AND VALUE OF AN ENFORCED DISPLACE-        $
                         $        MENT.                                                           $
                         $                                                                        $
                         $       SID     G       C       D
                         SPC     13      11      35
                         $                                                                        $
                         $        THE SUPORT ENTRY IDENTIFIES A GRID POINT OR A SCALAR POINT      $
                         $        AND SPECIFIES THE DOF COMPONENTS IN WHICH THE USER DESIRES      $
                         $        REACTIONS TO BE APPLIED TO PREVENT RIGID BODY MOTION.  IT       $
                         $        THUS INVOKES THE SOLUTION OF THE BALANCE EQUATIONS TO DETER-    $
                         $        MINE THE REACTIONS.  IN THE STATIC AEROELASTIC SOLUTION         $
                         $        THE DOF COMPONENTS MUST BE CONSISTENT WITH THE UNDEFINED        $
                         $        VARIABLES ON THE TRIM ENTRIES.                                  $
                         $                                                                        $
                         SUPORT  11      4
                         $                                                                        $
                         $                                                                        $
                         $                     * * * AERODYNAMIC DATA * * *                       $
                         $                                                                        $
                         $                          (LB-IN-SEC SYSTEM)                            $
                         $                                                                        $
                         $                       * * ELEMENT GEOMETRY * *                         $
                         $                                                                        $
                         $        THE AEROS ENTRY IS UNIQUE TO THE STATIC AEROELASTICITY          $
                         $        SOLUTION, SOL144.  ACSID IDENTIFIES THE AERO COORDINATE         $
                         $        SYSTEM.  RCSID IDENTIFIES THE REFERENCE COORDINATE SYS-         $
                         $        TEM FOR RIGID BODY MOTION.  REFC IS THE REFERENCE CHORD.        $
                         $        REFB IS THE REFERENCE SPAN.  REFS IS THE REFERENCE WING         $
                         $        AREA.  SYMXZ AND SYMXY ARE SYMMETRY KEYS.                       $
                         $                                                                        $
                         $       ACS     RCID    CHORD   SPAN    AREA    SYMYZ   SYMXY
                         AEROS   1       1       162.5   1000.0  81250.0 -1
                         $                                                                        $
                         $                                                                        $
                         $                    * CONTROL SURFACE DEFINITION *                      $
```

Listing 7-7 Input Files for Jet Transport Wing in Roll (Continued)

```
EXAMPLE HA144B: BAH JET TRANSPORT WING DYNAMIC ANALYSIS                                PAGE     8
 ANTISYMMETRIC,  58 BOXES, DOUBLET-LATTICE AERO
 AILERON ROLL, STATIC AERO SOLUTION
                                             I N P U T   B U L K   D A T A   D E C K   E C H O

                         .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                         $                                                                       $
                         $        THE AESURF ENTRY DEFINES AN AERODYNAMIC CONTROL SURFACE.       $
                         $        LISTED ARE THE ALPHANUMERIC NAME OF THE SURFACE, THE ID        $
                         $        OF A COORDINATE SYSTEM THAT DEFINES THE HINGE LINE AND         $
                         $        THE ID OF AN AELIST ENTRY.                                     $
                         $                                                                       $
                         $       ID      LABEL   CID1    ALID1   CID2    ALID2
                         AESURF  503     AILE    10      2005
                         $                                                                       $
                         $        THE CORD2R ENTRY DEFINES THE COORDINATE SYSTEM IN WHICH THE    $
                         $        HINGE-LINE IS DEFINED.  IT LISTS THE ORIGIN, A POINT ALONG     $
                         $        THE Z-AXIS AND A POINT IN THE X-Z PLANE.                       $
                         $                                                                       $
                         $       CID     RID     A1      A2      A3      B1      B2      B3
                         CORD2R  10              -90.0   0.      0.      -90.0   0.      1.      +CR10
                         $       C1      C2      C3
                         +CR10   410.0   -50.0   0.0
                         $                                                                       $
                         INCLUDE BAH_AERO58.DAT
                         $                                                                       $
                         $        THE AELIST ENTRY LISTS AERODYNAMIC BOXES THAT LIE ON THE       $
                         $        CONTROL SURFACE.                                               $
                         $                                                                       $
                         $       SID     E1      E2      E3      ETC
                         AELIST  2005    2005    2006    2011    2012    2017    2018
                         $                                                                       $
                         $                * BEAM SPLINE FIT ON THE AILERON *                     $
                         $                                                                       $
                         $        THE SPLINE1 ENTRY DEFINES A SURFACE SPLINE FOR INTERPO-        $
                         $        LATING OUT-OF-PLANE DISPLACEMENTS FROM THE STRUCTURAL          $
                         $        GRID POINTS ON THE SETG ENTRY TO THE SUB-REGION DEFINED        $
                         $        BY AERODYNAMIC BOXES 2005 THRU 2018 OF THE REGION ON THE       $
                         $        CAERO1 ENTRY.  DZ=0 SPECIFIES THAT NO SMOOTHING OF THE         $
                         $        SPLINE IS TO BE IMPOSED.                                       $
                         $                                                                       $
                         $       EID     CAERO   BOX1    BOX2    SETG    DZ
                         SPLINE1 104     2001    2005    2018    15
                         $                                                                       $
                         $        THE SET1 ENTRY DEFINES THE SETS OF POINTS TO BE USED BY        $
                         $        THE SURFACE SPLINE FOR INTERPOLATION.                          $
                         $                                                                       $
                         $       SID     G1      G2      G3      G4      G5      G6
                         SET1    15      8       10      12
                         $                                                                       $
                         $                                                                       $
                         $                  * * * SOLUTION SPECIFICATIONS * * *                  $
                         $                                                                       $
                         $                       * * AERODYNAMIC DOFS * *                        $
                         $                                                                       $
                         $        THE AESTAT ENTRY LISTS TRIM VARIABLES USED TO SPECIFY          $
                         $        RIGID BODY MOTIONS.  THESE AND THE CONTROL SURFACE             $
                         $        ROTATIONS MAKE UP THE VARIABLES IN THE EQUATIONS OF            $
                         $        MOTION.                                                        $
                         $                                                                       $
                         AESTAT  501     ROLL
                         AESTAT  502     URDD4
                         $                                                                       $
                         $                        * * TRIM CONDITIONS * *                        $
                         $                                                                       $
                         $        THE TRIM ENTRY SPECIFIES CONSTRAINTS FOR THE TRIM VARIABLES    $
                         $        LISTED ON THE AESTAT AND AESURF ENTRIES.  LISTED ARE ITS ID,   $
                         $        THE MACH NUMBER, DYNAMIC PRESSURE AND PAIRS OF TRIM VARI-      $
                         $        ABLES AND THEIR CONSTRAINED VALUES.  THOSE THAT ARE NOT        $
                         $        HELD FIXED MUST BE CONSTRAINED BY REACTION FORCES STIPU-       $
                         $        LATED ON THE SUPORT ENTRY.  SEE SECTION 3.5.3 OF THE THEO-     $
                         $        RETICAL MANUAL FOR MORE DETAILS.                               $
                         $                                                                       $
                         $        TRIM CONDITION 1:  STEADY ROLL                                 $
                         $                                                                       $
                         $       ID      MACH    Q       LABEL1  UX1     LABEL2  UX2             $
                         TRIM    1       0.0     4.0075  URDD4   0.0     AILE    1.0
                         $                                                                       $
                         $        THE PARAM,AUNITS,GINV PERMITS THE ACCELERATIONS ON THE TRIM
                         $        ENTRY TO BE SPECIFIED IN UNITS OF LOAD FACTOR (that is, IN G'S)
                         $
                         PARAM   AUNITS  .0025907
                         $
                         ENDDATA
                         INPUT BULK DATA CARD COUNT =     430
```

Listing 7-8 Sorted Bulk Data Entries for Jet Transport Wing in Roll

```
EXAMPLE HA144B: BAH JET TRANSPORT WING DYNAMIC ANALYSIS                                                 PAGE    12
 ANTISYMMETRIC,  58 BOXES, DOUBLET-LATTICE AERO
 AILERON ROLL, STATIC AERO SOLUTION
                                             S O R T E D   B U L K   D A T A   E C H O
           CARD
           COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
              1-        AEFACT  1       0.      .09     .21     .33     .45     .56     .66     +AE1
              2-        +AE1    .74
              3-        AEFACT  2       .74     .82     .90     .974
              4-        AEFACT  3       .974    1.00
              5-        AEFACT  4       0.      .1875   .375    .625    .750    .875    1.00
              6-        AELIST  2005    2005    2006    2011    2012    2017    2018
              7-        AEROS   1       1       162.5   1000.0  81250.0 -1
              8-        AESTAT  501     ROLL
              9-        AESTAT  502     URDD4
             10-        AESURF  503     AILE    10      2005
             11-        CAERO1  1001    1000    0               5       1               1       +CA1
             12-        +CA1    78.75   0.      0.      225.    35.     500.    0.      100.
             13-        CAERO1  2001    1000    0                       2       4       1       +CA2
             14-        +CA2    78.75   0.      0.      225.    35.     500.    0.      100.
             15-        CAERO1  3001    1000    0               5       3               1       +CA3
             16-        +CA3    78.75   0.      0.      225.    35.     500.    0.      100.
             17-        CELAS2  3       5142661.12      5
             18-        CMASS2  121     5248.7  1       3
             19-        CMASS2  122     134.9   1       3       2       3
             20-        CMASS2  123     790.3   2       3
             21-        CMASS2  341     9727.   3       3
             22-        CMASS2  342     11005.  3       3       4       3
             23-        CMASS2  343     473.    4       3
             24-        CMASS2  561     3253.6  5       3
             25-        CMASS2  562     -139.7  5       3       6       3
             26-        CMASS2  563     946.3   6       3
             27-        CMASS2  781     2617.8  7       3
             28-        CMASS2  782     21.     7       3       8       3
             29-        CMASS2  783     782.3   8       3
             30-        CMASS2  9101    494.8   9       3
             31-        CMASS2  9102    -7.3    9       3       10      3
             32-        CMASS2  9103    185.2   10      3
             33-        CONM1   1       11                                                      +51
             34-        +51     17400.                          4.37+7                          +52
             35-        +52             4.35+09
             36-        CONM1   2       12                                                      +AIL1
             37-        +AIL1   0.0                                                     0.0     +AIL2
             38-        +AIL2           13970.5
             39-        CORD2R  1               0.      0.      0.      0.      0.      -1.     +C1
             40-        +C1     -1.     0.      0.
             41-        CORD2R  10              -90.0   0.      0.      -90.0   0.      1.      +CR10
             42-        +CR10   410.0   -50.0   0.0
             43-        GENEL   432             1       3       2       3       3       3       +01
             44-        +01     4       3       5       3       6       3       7       3       +02
             45-        +02     8       3       9       3       10      3                       +03
             46-        +03     UD              11      3       11      4       11      5       +04
             47-        +04     11      6                                                       +05
             48-        +05     Z       8.7172-61.3361-61.2778-56.2720-61.6251-51.0492-52.0478-5+06
             49-        +06     1.5630-52.4285-52.0403-53.0861-56.2720-63.2297-51.0492-53.3529-5+07
             50-        +07     1.5630-53.5021-52.0257-53.5785-52.7732-51.5726-54.8255-53.7628-5+08
             51-        +08     7.3284-56.4338-59.5810-58.8378-56.3749-53.7628-58.0136-56.4338-5+09
             52-        +09     1.0012-48.8378-51.1811-41.2758-41.1344-41.9350-41.8160-42.5283-4+10
             53-        +10     2.4294-41.6999-41.8160-42.2920-42.4294-42.8249-43.6862-43.5052-4+11
             54-        +11     5.2675-45.1171-44.2292-45.1171-45.7187-48.4840-48.2340-49.2340-4+12
             55-        +12     S       1.0     90.0    -20.25  45.0    1.0     90.0    81.0    +13
             56-        +13     45.0    1.0     186.0   -17.85  141.0   1.0     186.0   71.4    +14
             57-        +14     141.0   1.0     268.0   -15.80  223.0   1.0     268.0   63.2    +15
             58-        +15     223.0   1.0     368.0   -13.30  323.0   1.0     368.0   53.2    +16
             59-        +16     323.0   1.0     458.0   -11.05  413.0   1.0     458.0   44.2    +17
             60-        +17     413.0
             61-        GRID    1               20.25   90.                     12456
             62-        GRID    2               -81.    90.                     12456
             63-        GRID    3               17.85   186.                    12456
             64-        GRID    4               -71.4   186.                    12456
             65-        GRID    5               15.8    268.                    12456
             66-        GRID    6               -63.2   268.                    12456
             67-        GRID    7               13.3    368.                    12456
             68-        GRID    8               -53.2   368.                    12456
             69-        GRID    9               11.05   458.                    12456
             70-        GRID    10              -44.2   458.                    12456
```

Listing 7-8 Sorted Bulk Data Entries for Jet Transport Wing in Roll (Continued)

```
71-        GRID    11              0.0     0.                      126
72-        GRID    12              -86.45  368.                    1246
73-        MPC     1       12      3       -1.0    8       3       1.5             +MPC1
74-        +MPC1           7       3       -0.5    12      5       33.25
75-        PAERO1  1000
76-        PARAM   AUNITS  .0025907
77-        PARAM   GRDPNT  11
78-        PARAM   WTMASS  .0025907
79-        SET1    14      1       THRU    11
80-        SET1    15      8       10      12
81-        SPC     13      11      35
82-        SPLINE1 104     2001    2005    2018    15
83-        SPLINE2 101     1001    1001    1035    14      0.      1.      0       +SP1
84-        +SP1    -1.0    -1.0
85-        SPLINE2 102     2001    2001    2016    14      0.      1.      0       +SP2
86-        +SP2    -1.0    -1.0
87-        SPLINE2 103     3001    3001    3005    14      0.      1.      0       +SP3
88-        +SP3    -1.0    -1.0
89-        SUPORT  11      4
90-        TRIM    1       0.0     4.0075  URDD4   0.0     AILE    1.0
           ENDDATA
    TOTAL COUNT=    91
```

Listing 7-9 Output for Jet Transport Wing in Roll

```
EXAMPLE HA144B: BAH JET TRANSPORT WING DYNAMIC ANALYSIS                                               PAGE    15
 ANTISYMMETRIC,  58 BOXES, DOUBLET-LATTICE AERO
 AILERON ROLL, STATIC AERO SOLUTION
                       O U T P U T   F R O M   G R I D   P O I N T   W E I G H T   G E N E R A T O R
                                                    REFERENCE POINT =       11
                                                              M O
                  *  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00 *
                  *  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00 *
                  *  0.000000E+00  0.000000E+00  4.191900E+04  5.128960E+06 -1.642074E+05  0.000000E+00 *
                  *  0.000000E+00  0.000000E+00  5.128960E+06  1.350243E+09 -2.381847E+07  0.000000E+00 *
                  *  0.000000E+00  0.000000E+00 -1.642074E+05 -2.381847E+07  4.458796E+09  0.000000E+00 *
                  *  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00 *
                                                              S
                                       *  1.000000E+00  0.000000E+00  0.000000E+00 *
                                       *  0.000000E+00  1.000000E+00  0.000000E+00 *
                                       *  0.000000E+00  0.000000E+00  1.000000E+00 *
                           DIRECTION
                      MASS AXIS SYSTEM (S)      MASS              X-C.G.        Y-C.G.        Z-C.G.
                              X            0.000000E+00      0.000000E+00  0.000000E+00  0.000000E+00
                              Y            0.000000E+00      0.000000E+00  0.000000E+00  0.000000E+00
                              Z            4.191900E+04      3.917256E+00  1.223541E+02  0.000000E+00
                                                              I(S)
                                       *  7.226942E+08  3.727022E+06  0.000000E+00 *
                                       *  3.727022E+06  4.458153E+09  0.000000E+00 *
                                       *  0.000000E+00  0.000000E+00  0.000000E+00 *
                                                              I(Q)
                                       *  4.458157E+09                             *
                                       *                7.226906E+08               *
                                       *                              0.000000E+00 *
                                                               Q
                                       *  9.977400E-04  9.999995E-01  0.000000E+00 *
                                       * -9.999995E-01  9.977400E-04  0.000000E+00 *
                                       *  0.000000E+00  0.000000E+00  1.000000E+00 *

N O N - D I M E N S I O N A L   S T A B I L I T Y   A N D   C O N T R O L   D E R I V A T I V E   C O E F F I C I
E N T S

                                     MACH = 0.0000E+00                   Q = 4.0075E+00

             TRANSFORMATION FROM BASIC TO REFERENCE COORDINATES:
          { X }         [ -1.0000    0.0000    0.0000  ]  { X }         { 0.0000E+00 }
          { Y }    =    [  0.0000    1.0000    0.0000  ]  { Y }      +  { 0.0000E+00 }
          { Z }REF      [  0.0000    0.0000   -1.0000  ]  { Z }BAS      { 0.0000E+00 }

TRIM VARIABLE         COEFFICIENT              RIGID                              ELASTIC
                                        UNSPLINED        SPLINED           RESTRAINED      UNRESTRAINED
INTERCEPT                CX            0.000000E+00     0.000000E+00         0.000000E+00    0.000000E+00
                         CY            0.000000E+00     0.000000E+00         0.000000E+00    0.000000E+00
                         CZ            0.000000E+00     0.000000E+00         0.000000E+00    0.000000E+00
                         CMX           0.000000E+00     0.000000E+00         0.000000E+00    0.000000E+00
                         CMY           0.000000E+00     0.000000E+00         0.000000E+00    0.000000E+00
                         CMZ           0.000000E+00     0.000000E+00         0.000000E+00    0.000000E+00

ROLL                     CX            0.000000E+00     0.000000E+00         0.000000E+00    0.000000E+00
                         CY            0.000000E+00     0.000000E+00         0.000000E+00    0.000000E+00
                         CZ            0.000000E+00     0.000000E+00         0.000000E+00    0.000000E+00
                         CMX          -4.414531E-01    -4.414531E-01        -5.189431E-01   -5.059597E-01
                         CMY           0.000000E+00     0.000000E+00         0.000000E+00    0.000000E+00
                         CMZ           0.000000E+00     0.000000E+00         0.000000E+00    0.000000E+00

URDD4                    CX            0.000000E+00     0.000000E+00         0.000000E+00    0.000000E+00
                         CY            0.000000E+00     0.000000E+00         0.000000E+00    0.000000E+00
                         CZ            0.000000E+00     0.000000E+00         0.000000E+00    0.000000E+00
                         CMX           0.000000E+00     0.000000E+00        -1.064108E-01    0.000000E+00
                         CMY           0.000000E+00     0.000000E+00         0.000000E+00    0.000000E+00
                         CMZ           0.000000E+00     0.000000E+00         0.000000E+00    0.000000E+00

AILE                     CX            0.000000E+00     0.000000E+00         0.000000E+00    0.000000E+00
                         CY            0.000000E+00     0.000000E+00         0.000000E+00    0.000000E+00
                         CZ            0.000000E+00     0.000000E+00         0.000000E+00    0.000000E+00
                         CMX           1.448708E-01     1.448708E-01         1.054927E-01    1.028534E-01
                         CMY           0.000000E+00     0.000000E+00         0.000000E+00    0.000000E+00
                         CMZ           0.000000E+00     0.000000E+00         0.000000E+00    0.000000E+00

                                              INTERMEDIATE MATRIX ... HP
                                                        COLUMN       1
                                                   3.054546E-01
                                                        COLUMN       2
                                                   2.098385E+00
                                                        COLUMN       3
                                                  -7.304801E-02
```

Listing 7-9 Output for Jet Transport Wing in Roll (Continued)

```
                         A E R O S T A T I C   D A T A   R E C O V E R Y   O U T P U T   T A B L E
                                      AEROELASTIC TRIM VARIABLES
                                     TRIM VARIABLE    VALUE OF UX

                                        ROLL          2.032838E-01
                                        URDD4         0.000000E+00
                                        AILE          1.000000E+00

                         A E R O S T A T I C   D A T A   R E C O V E R Y   O U T P U T   T A B L E
                                MACH = 0.000000E+00                       Q = 4.007500E+00
                                                                                   AERODYNAMIC FORCES
          AERODYNAMIC          AERODYNAMIC PRES.    AERODYNAMIC
             GRID   LABEL     COEFFICIENTS         PRESSURES          EXTERNAL ID  LABEL  NORMAL FORCES(T3)
MOMENTS(R2)
              1      LS     -1.354849E-01      -5.429556E-01            1001   LS    -1.071998E+03    -
1.175848E+04
              2      LS     -4.765255E-02      -1.909676E-01            1002   LS    -3.770417E+02    -
4.135676E+03
              3      LS     -2.612218E-02      -1.046846E-01            1003   LS    -2.066867E+02    -
2.267095E+03
              4      LS     -1.495107E-02      -5.991640E-02            1004   LS    -1.182974E+02    -
1.297575E+03
              5      LS     -7.376158E-03      -2.955995E-02            1005   LS    -5.836243E+01    -
6.401630E+02
              6      LS     -3.648801E-01      -1.462257E+00            1006   LS    -3.619086E+03    -
3.732182E+04
              7      LS     -1.464361E-01      -5.868426E-01            1007   LS    -1.452435E+03    -
1.497824E+04
              8      LS     -8.362006E-02      -3.351074E-01            1008   LS    -8.293911E+02    -
8.553097E+03
              9      LS     -4.900119E-02      -1.963723E-01            1009   LS    -4.860213E+02    -
5.012094E+03
             10      LS     -2.503084E-02      -1.003111E-01            1010   LS    -2.482700E+02    -
2.560284E+03
             11      LS     -6.398618E-01      -2.564246E+00            1011   LS    -5.884946E+03    -
5.627479E+04
             12      LS     -2.556842E-01      -1.024655E+00            1012   LS    -2.351582E+03    -
2.248700E+04
             13      LS     -1.459844E-01      -5.850326E-01            1013   LS    -1.342650E+03    -
1.283910E+04
             14      LS     -8.575688E-02      -3.436707E-01            1014   LS    -7.887239E+02    -
7.542170E+03
             15      LS     -4.417319E-02      -1.770241E-01            1015   LS    -4.062703E+02    -
3.884959E+03
             16      LS     -9.208332E-01      -3.690239E+00            1016   LS    -7.804856E+03    -
6.878029E+04
             17      LS     -3.609245E-01      -1.446405E+00            1017   LS    -3.059147E+03    -
2.695873E+04
             18      LS     -2.014354E-01      -8.072526E-01            1018   LS    -1.707340E+03    -
1.504593E+04
             19      LS     -1.155547E-01      -4.630855E-01            1019   LS    -9.794256E+02    -
8.631187E+03
             20      LS     -5.842042E-02      -2.341198E-01            1020   LS    -4.951635E+02    -
4.363628E+03
             21      LS     -1.163823E+00      -4.664021E+00            1021   LS    -8.304871E+03    -
6.721755E+04
             22      LS     -4.398006E-01      -1.762501E+00            1022   LS    -3.138353E+03    -
2.540105E+04
             23      LS     -2.303485E-01      -9.231217E-01            1023   LS    -1.643734E+03    -
1.330397E+04
             24      LS     -1.207852E-01      -4.840466E-01            1024   LS    -8.619053E+02    -
6.976046E+03
             25      LS     -5.559115E-02      -2.227816E-01            1025   LS    -3.966904E+02    -
3.210713E+03
             26      LS     -1.347419E+00      -5.399781E+00            1026   LS    -8.032175E+03    -
5.973930E+04
             27      LS     -4.651038E-01      -1.863904E+00            1027   LS    -2.772556E+03    -
2.062088E+04
             28      LS     -1.955689E-01      -7.837424E-01            1028   LS    -1.165817E+03    -
8.670762E+03
             29      LS     -5.785358E-02      -2.318482E-01            1029   LS    -3.448742E+02    -
2.565002E+03
             30      LS     -1.905612E-03      -7.636740E-03            1030   LS    -1.135965E+01    -
8.448740E+01
             31      LS     -1.437025E+00      -5.758880E+00            1031   LS    -6.334769E+03    -
4.355154E+04
             32      LS     -4.041525E-01      -1.619641E+00            1032   LS    -1.781605E+03    -
1.224854E+04
             33      LS     -2.264492E-02      -9.074951E-02            1033   LS    -9.982446E+01    -
6.862932E+02
            34      LS     2.357795E-01      9.448866E-01            1034   LS     1.039375E+03     7.145705E+03
            35      LS     2.615480E-01      1.048154E+00            1035   LS     1.152969E+03     7.926661E+03
             36      LS     -1.530291E+00      -6.132641E+00            2001   LS    -5.864338E+03    -
3.504858E+04
             37      LS     -3.360160E-01      -1.346584E+00            2002   LS    -1.287671E+03    -
```

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Listing 7-9 Output for Jet Transport Wing in Roll (Continued)

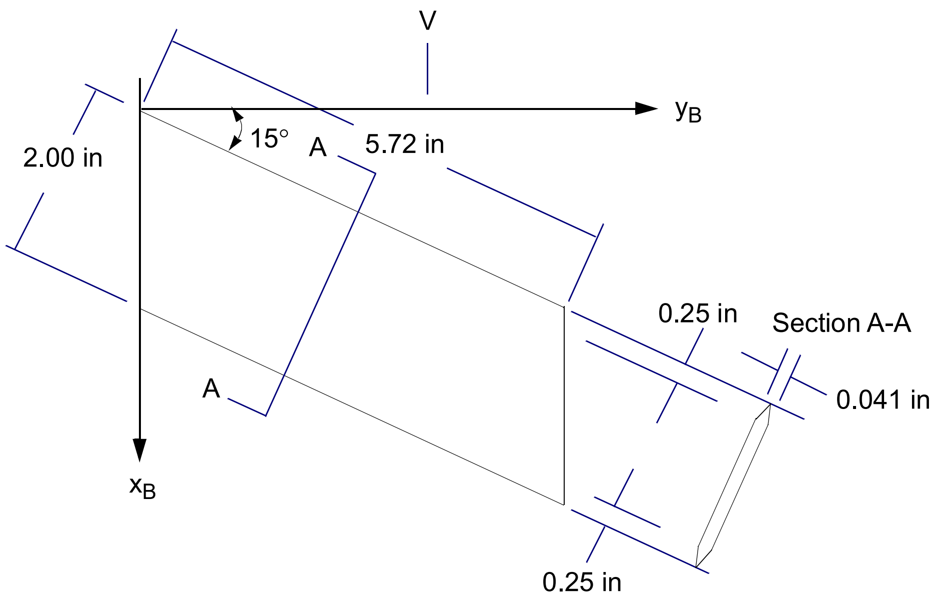
```
7.695847E+03
              38     LS      2.695004E-01        1.080023E+00             2003   LS     1.377029E+03      1.097320E+04
              39     LS      1.497109E+00        5.999664E+00             2004   LS     3.824786E+03      1.523938E+04
              40     LS      3.661325E+00        1.467276E+01             2005   LS     9.353885E+03      3.726939E+04
              41     LS      1.145043E+00        4.588762E+00             2006   LS     2.925336E+03      1.165563E+04
                42     LS     -1.569205E+00       -6.288589E+00             2007   LS     -5.541820E+03     -
3.052331E+04
                43     LS     -2.701145E-01       -1.082484E+00             2008   LS     -9.539389E+02     -
5.254117E+03
              44     LS      4.182711E-01        1.676221E+00             2009   LS     1.969560E+03      1.446396E+04
              45     LS      1.815431E+00        7.275338E+00             2010   LS     4.274261E+03      1.569455E+04
              46     LS      4.017232E+00        1.609906E+01             2011   LS     9.458201E+03      3.472934E+04
              47     LS      1.380969E+00        5.534232E+00             2012   LS     3.251362E+03      1.193859E+04
                48     LS     -1.562750E+00       -6.262719E+00             2013   LS     -4.686912E+03     -
2.370004E+04
                49     LS     -2.563097E-01       -1.027161E+00             2014   LS     -7.687097E+02     -
3.887089E+03
              50     LS      3.775468E-01        1.513019E+00             2015   LS     1.509757E+03      1.017906E+04
              51     LS      1.684529E+00        6.750751E+00             2016   LS     3.368097E+03      1.135417E+04
              52     LS      3.921867E+00        1.571688E+01             2017   LS     7.841497E+03      2.643442E+04
              53     LS      1.306940E+00        5.237563E+00             2018   LS     2.613135E+03      8.809122E+03
                54     LS     -1.122619E+00       -4.498896E+00             3001   LS     -1.188721E+03     -
6.040188E+03
                55     LS     -1.255417E-01       -5.031084E-01             3002   LS     -1.329338E+02     -
6.754702E+02
              56     LS      2.223080E-01        8.908994E-01             3003   LS     2.353979E+02      1.196116E+03
              57     LS      6.150346E-01        2.464751E+00             3004   LS     6.512489E+02      3.309158E+03
              58     LS      8.130676E-01        3.258368E+00             3005   LS     8.609423E+02      4.374663E+03
     *** LABEL NOTATIONS:  LS = LIFTING SURFACE,  ZIB = Z INTERFERENCE BODY ELEMENT,  ZSB = Z SLENDER BODY
ELEMENT,
                                                YIB = Y INTERFERENCE BODY ELEMENT,  YSB = Y SLENDER BODY ELEMENT.

                                        D I S P L A C E M E N T   V E C T O R

  POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
         7      G       0.0            0.0           -5.400196E+00   0.0            0.0            0.0
         8      G       0.0            0.0           -1.110230E+01   0.0            0.0            0.0
         9      G       0.0            0.0           -1.101022E+01   0.0            0.0            0.0
        10      G       0.0            0.0           -1.777396E+01   0.0            0.0            0.0
        11      G       0.0            0.0            0.0            0.0            0.0            0.0
        12      G       0.0            0.0           -1.563730E+01   0.0           -5.064504E-02   0.0
```

15-Degree Sweptback Wing in a Wind Tunnel

A simple flat-plate wing with 15 deg of sweepback is shown in Figure 7-10. This wing has been tested in a wind tunnel for flutter at subsonic and supersonic speeds, and the results have been reported by Tuovila and McCarty (1955) [Reference 60]. A number of models of the same shape, but of different materials, were tested. The models were made of 0.041 in thick sheet metal with their leading and trailing edges beveled 0.25 in to form a symmetric hexagonal airfoil shape. The 15 deg swept model had a constant chord of 2.07055 in. and a semispan of 5.52510 in. (and an effective span with wall reflection of 11.0502 in). The low-speed models were made of aluminum, and the high-speed models were made of magnesium. The subsonic flutter test was run at Mach number $m = 0.45$. In the present example, the aluminum model is treated as if it were tested for its static aeroelastic characteristics in the wind tunnel at $m = 0.45$.



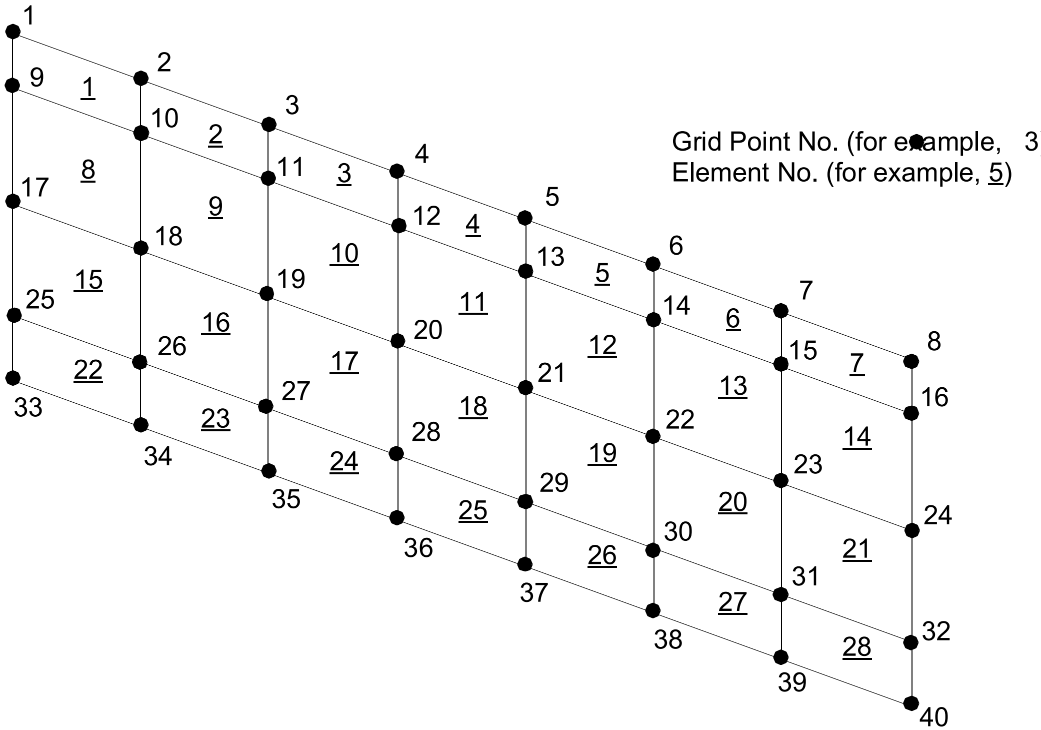
Planform and Cross Section

Figure 7-10 A 15-Degree Sweptback Wing Model

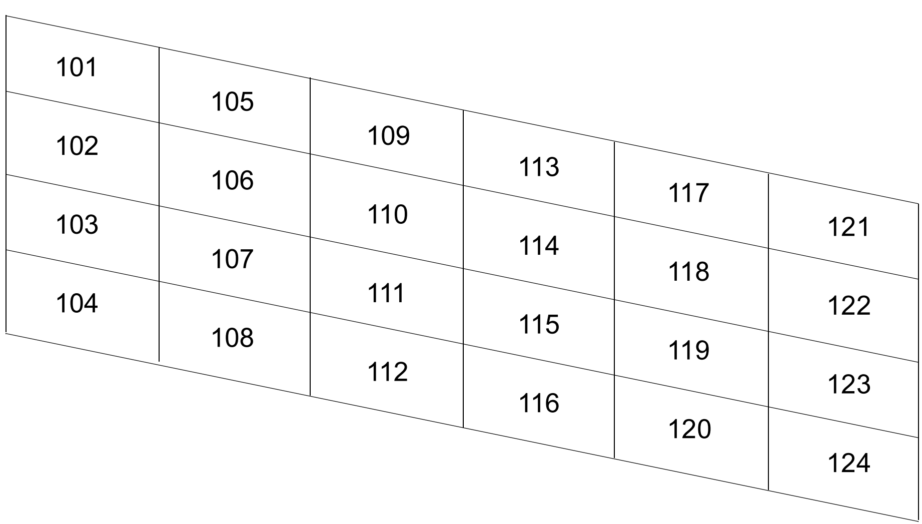
A cantilevered analysis is used to represent affixing the model to the wind tunnel wall.

The present example represents the plate model appropriately by plate elements. The basic structural model consists of GRID and CQUAD4 entries. The plate wing is divided into seven strips of equal width and four chordwise elements separated along the one-eighth, one-half, and seven-eighths chord lines; its idealization into 28 structural plate elements is shown in Figure 7-11 (a). The leading- and trailing-edge CQUAD4 elements taper in thickness to zero at the edges on their corresponding CQUAD4 entries, whereas the interior elements have the constant thickness of 0.041 in. as given on the PSHELL entry. The MAT1 entry lists the moduli $E = 10.3 \times 10^6$ psi and $G = 3.9 \times 10^6$ psi, and the weight density of $\rho = 0.100$ lb/in^3 for aluminum. Three grid points are constrained to simulate a perfectly clamped root chord. However, the root leading and trailing edge grid points are assumed to be free because a clamp would not restrain the beveled edges. GRIDs 9 and 25 (at the one-eighth and seven-eighths chord points at the root) are connected to GRID 17 by rigid bars (RBAR 101 and RBAR 102), and GRID 17 is constrained in all degrees of freedom. GRIDs 1 through 8, 10 through 16, 18 through 24, and 26 through 40 are constrained against in-plane rotation (R3) because the CQUAD4 element has no in-plane rotational stiffness. This plate model is used in several subsequent examples. The Bulk Data entries are contained in the separate input file PLATEST. DAT that is presented in Listing 7-10.

The density on the MAT1 entry and PARAM,COUPMASS,1 result in the generation of the coupled (note that a coupled mass matrix is not a consistent mass matrix) mass matrix of the plate, while the GRAV entry introduces the weight of the model into the problem. Although the weight of a wind tunnel model is usually small, it is not negligible and is just as easily included. The additional PARAM,AUNITS is included to permit accelerations to be specified in units of Gs both in the input (on the TRIM entry) and in the output (the values of the UX for accelerations in the Aerostatic Data Recovery Output Table). The LOAD entry applies the gravity load.



(a) Structural Grid Point and CQUAD 4 Elements



(b) Aerodynamic Model

Figure 7-11 A 15-Degree Sweptback Wing Model

The Aerodynamic Model

The aerodynamic data begin with the AEROS entry, which includes the reference chord of 2.07055 in., the reference span (twice the exposed span) of 11.0502 in., the exposed surface area of 11.4400 sq in., and the symmetry flags SYMXZ = 1 to account for the wind tunnel wall reflection and SYMXY = 0 to neglect tunnel floor and ceiling interference. The aerodynamic coordinate system CORD2R has its origin at the wing support point (GRID 17) and its positive x-axis aft in the streamwise direction. The CAERO1 entry, along with a subsonic Mach number on the TRIM entry, specifies the subsonic Doublet-Lattice method. Six equal width spanwise strips are specified along with the minimum recommended number of four equal chordwise strips. The planform geometry is specified on the continuation entry. A PAERO1 entry is required although there are no interfering bodies in the problem. The division of the planform into aerodynamic boxes is shown in Figure 7-11(b).

Spline Data

The aerodynamics and structure are interconnected by a surface spline SPLINE1. The 24 aerodynamic boxes are tied to the 17 grid points listed on the SET1 entries. The 17 points are variously spaced spanwise from the root to tip and along the leading edge, the one-eighth, one-half, and seven-eighth chord lines, and the trailing edge and do not include any grids that are fixed.

The optional user input of downwashes caused by incidence, twist, or camber is illustrated by the direct matrix input item W2GJ. The additional downwashes w_j^g [See (2-2)] at the three-quarter chord location of each aerodynamic box are input in this manner. In this example, it is assumed that the model has no camber or twist and is set in the wind tunnel at an angle of attack of 10 deg = 0.17453 rad so that W2GJ is constant for the 24 boxes.

Static Aeroelastic Inputs

The static aeroelastic solution requires the definition of the trim variables. Normally, both AESTAT and AESURF entries are required. However, in this example there is no trimming surface required since the model is cantilevered and only a stress analysis is being performed. The trim variables, angle of attack $\alpha = \mathrm{ANGLEA}$, pitch rate $qc/2V = \mathrm{PITCH}$, vertical acceleration $\ddot{z}/g = \mathrm{URDD3}$, and pitching acceleration $\dot{q}/g = \mathrm{URDD5}$ are listed on four AESTAT entries. TRIM entries are present for the two trim subcases. The first entry specifies the Mach number $m = 0.45$, the dynamic pressure $\bar{q} = 2.0\ \mathrm{psi}$, the angle of attack $\alpha = 0.0$ (since the wind tunnel setting has already been included as 10.0 deg of incidence), the pitch rate $q\bar{c}/2V = 0.0$ and $URDD3 = URDD5 = 0$. The second trim entry is identical except the dynamic pressure is now $\dot{q} = 4.0$ psi. A 1g Gravity load is applied.

Monitor Points

The input includes four MONPNT3 entries and a single MONSUM to illustrate the use of these entries. The MONPNT3 entries entail four cuts along the span of the wing with names and labels that describe the purpose of the entries.

- OUTBD - This monpnt3 makes a cut along the span extending from grid point 5 to 37 that provides the net loads at the cut without including the loads on the grids. As detailed in the *MSC Nastran Quick Reference Guide* description of the MONPNT3, the XFLAG=SMAD in this case provides the summation of element loads on the upstream/outboard portion of the cut without any grid point loads.
- OUTBDA – This monpnt3 uses the same element and grids sets as OUTBD, but now with the XFLAG field blank, it sums the element loads on the downstream/inboard portion of the cut while including grid point loads.
- INBD – this monpnt3 makes a cut along the span extending from grid point 2 to 34 while again excluding all the available load types.
- ROOT – This monpnt3 contains the elements and grids at the root, excluding all available load types.
- ROOTM – This MONSUM provides units conversions to the ROOT monpnt3 by leaving the translational results unchanged and multiplying the moments by 12.

Case Control Commands

The Case Control Section begins with three title commands that appear at the top of each page of output and at the bottom of each output plot. Using ECHO = BOTH prints both the annotated and sorted Bulk Data Sections with the output. The SPC and LOAD commands invoke the corresponding Bulk Data entries (SPC1 and GRAV). The DISP = ALL, STRESS = ALL, FORCE = ALL, AEROF = ALL, APRES = ALL, GPFORCES = ALL and MONITOR = ALL commands are print requests for structural deflections, stresses, forces, aerodynamic forces and pressures, grid point forces and monitor point results. The TRIM command selects the trim condition from the Bulk Data Section for the two subcases. The TRIMF command requests the output of the trim loads as FORCE (MOMENT) bulk data entries. Options request separate applied and aerodynamic loads in addition to the default elastic total loads. Note that all the loads include effects of the aeroelastic deformation.

In the Executive Control Section, ID MSC, HA144C is the identification of this problem. TIME 5 limits the CPU time to 5 minutes. SOL 144 calls for the static aeroelastic response analysis. CEND completes the Executive Control Section.

Output

The input data file for this example is shown below in Listing 7-11 and output results for the first subcase are provided in Listing 7-12. Results of particular interest are reviewed in the following discussion.

The restrained stability derivatives are found for the model and are shown in Table 7-4. The unrestrained values are undefined for this cantilevered condition. Only a slight decrease in C_{L_α} is obtained along with a slight aft movement of the aerodynamic center at the high speed. The aerodynamic center in the rigid case is at

$$\Delta x/\bar{c} = C_{m_\alpha}/C_{L_\alpha} = -0.0695 = 6.95\%$$

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chord aft of the aerodynamic reference point, which is at the midchord of the root, or at 56.95% of the root chord. In the flexible case at $\bar{q} = 2.0 \text{ psi}$, the aerodynamic center has moved aft to 57.97% of the root chord. The pitch rate $(q\bar{c}/2V)$ and pitch acceleration $(\ddot{\theta}/g)$ derivatives provide additional information about the model but have no experimental counterpart. Note that the intercept coefficients are

$$C_{L_o} = C_{L_\alpha} w_j^g \text{ and } C_{m_o} = C_{m_\alpha} w_j^g$$

where the incidence

$$w_j^g = 0.17453 \text{ rad}$$

Table 7-4 Derivatives for the 15-Degree Swept Wind Tunnel Model

Derivative	Rigid Value	High Speed Value, $\bar{q}$ = 2.0 psi
C_{L_o}	0.7829	0.6800
C_{m_o}	-0.05443	-0.05508
C_{L_α}	4.486	3.89
C_{m_α}	-0.3119	-0.3156
C_{L_q}	5.204	2.854
C_{m_q}	-1.347	-1.117

Output data in SOL 144 is divided into two groups. The first group is for the aeroelastic results and the results for each subcase proceed in order before moving on to the next subcase. The second group is standard data recovery where all the types of data (such as displacements) are output together before moving to the next subcase. Following the stability derivatives, the first group includes trim variables, aerodynamic pressures and forces and monitor point responses. The trim variables are fixed at 0.0 for this cantilevered analysis. Selected monitor point results are shown in Table 7-5 and show how the shear forces and torque and bending moments vary along the span. As noted OUTBD and OUTBDA are at the same spanwise position, but OUTBDA includes the loads on the grid points while OUTBD does not. It is noted that the results at $\dot{q} = 4.0$ psi are less than two times those at Q=2.0 due to aeroelastic washout. ROOTM result is shown in the Listing 7-12, but not in Table 7-4 and simply shows an adjustment to the root result.

Table 7-5 Monitor Point Results for the 15-Degree Swept Wind Tunnel Model

		CZ		CMX		CMY	
Name	Span Station	q=2.0	q=4.0	q=2.0	q=4.0	q=2.0	q=4.0
OUTBD	3.157	4.411	7.241	5.682	9.303	1.104	1.566
OUTBDA	3.157	6.616	9.303	5.682	9.303	2.205	3.968
INBD	0.789	10.744	17.917	26.616	44.109	-1.272	-2.623
ROOT	0	15.533	26.810	46.651	78.216	-31.491	-59.931

The displacement and stress results show that the aerodynamic loads create deflections and stresses that are beyond the assumed small deflection theory even in the Q=2.0 case where the displacement at GRID 40 is 2.886 in. and the von Mises stress in CQUAD4 15 is 70,446.0 psi.

The final output of interest for this case are the trim loads that are output to the .pch file based on the TRIMF case control command. Listing 7-13 shows this file for the first subcase. There are no inertia loads for this case, so based on the TRIMF command, each subcase provides three loads:

- Elastic applied loads. These are the loads due to the GRAV request and include the aerodynamic contributions from the deflections.
- Elastic aerodynamic loads. Again, these are loads that include aeroelastic effects.
- Total elastic loads

If this third set of loads is applied to the model while invoking SOL 101 (statics), the static responses, including displacements, stresses and monitor point results, will be identical to those provided by SOL 144.

Listing 7-10 PLATEST.DAT Input File

```
$                                                                        $
$                    * * * STRUCTURAL DATA * * *                         $
$                                                                        $
$                         (LB-IN-SEC SYSTEM)                             $
$                                                                        $
$                       * * GRID GEOMETRY * *                            $
$                                                                        $
$        THE GRID ARRAY IS A FIVE BY EIGHT MESH OF EQUALLY SPACED        $
$        GRIDS IN THE SPANWISE DIRECTION AND UNEQUALLY SPACED GRIDS      $
$        IN THE CHORDWISE DIRECTION. CHORDWISE THE GRIDS ARE STATIONED   $
$        AT THE LEADING EGDE, 1/8 CHORD, 7/8 CHORD AND TRAILING EDGE.    $
$        THE WING HAS A 15 DEGREE SWEEP ANGLE.                           $
$                                                                        $
GRID    1                0.0     0.0     0.0
GRID    2                .211491 .7893   0.0
GRID    3                .422983 1.5786  0.0
GRID    4                .634474 2.3679  0.0
GRID    5                .845966 3.1572  0.0
GRID    6                1.05746 3.9465  0.0
GRID    7                1.26895 4.7358  0.0
GRID    8                1.48044 5.5251  0.0
GRID    9                .258819 0.0     0.0
GRID    10               .47031  .7893   0.0
GRID    11               .681802 1.5786  0.0
GRID    12               .893293 2.3679  0.0
GRID    13               1.10478 3.1572  0.0
GRID    14               1.31628 3.9465  0.0
GRID    15               1.52777 4.7358  0.0
GRID    16               1.73926 5.5251  0.0
GRID    17               1.03528 0.0     0.0
GRID    18               1.24677 .7893   0.0
GRID    19               1.45826 1.5786  0.0
GRID    20               1.66975 2.3679  0.0
GRID    21               1.88124 3.1572  0.0
GRID    22               2.09273 3.9465  0.0
GRID    23               2.30422 4.7358  0.0
GRID    24               2.51572 5.5251  0.0
GRID    25               1.81173 0.0     0.0
GRID    26               2.02322 .7893   0.0
GRID    27               2.23471 1.5786  0.0
GRID    28               2.44621 2.3679  0.0
GRID    29               2.6577  3.1572  0.0
GRID    30               2.86919 3.9465  0.0
GRID    31               3.08068 4.7358  0.0
GRID    32               3.29217 5.5251  0.0
GRID    33               2.07055 0.0     0.0
GRID    34               2.28204 .7893   0.0
GRID    35               2.49353 1.5786  0.0
GRID    36               2.70502 2.3679  0.0
GRID    37               2.91652 3.1572  0.0
GRID    38               3.12801 3.9465  0.0
GRID    39               3.3395  4.7358  0.0
GRID    40               3.55099 5.5251  0.0
$                                                                        $
$                                                                        $
$               * * STRUCTURAL STIFFNESS PROPERTIES * *                  $
$                                                                        $
$        THE ELEMENT CONNECTIVITY IS DEFINED BY THE CQUAD4 ENTRY. THE     $
$        PLATES ALONG THE LEADING AND TRAILING EDGES HAVE 0.0 IN.        $
$        THICKNESS BUT TAPER TO A CONTSTANT THICKNESS OF .041 IN.        $
$        BETWEEN THE 1/8 AND 7/8 CHORDS.                                 $
$                                                                        $
CQUAD4  1       1       1       2       10      9                       +M00000
+M00000                  0.0     0.0     .041    .041
CQUAD4  2       1       2       3       11      10                      +M00001
+M00001                  0.0     0.0     .041    .041
CQUAD4  3       1       3       4       12      11                      +M00002
+M00002                  0.0     0.0     .041    .041
CQUAD4  4       1       4       5       13      12                      +M00003
+M00003                  0.0     0.0     .041    .041
CQUAD4  5       1       5       6       14      13                      +M00004
+M00004                  0.0     0.0     .041    .041
CQUAD4  6       1       6       7       15      14                      +M00005
+M00005                  0.0     0.0     .041    .041
CQUAD4  7       1       7       8       16      15                      +M00006
+M00006                  0.0     0.0     .041    .041
```

Listing 7-10 PLATEST.DAT Input File (Continued)

```
CQUAD4  8       1       9       10      18      17
CQUAD4  9       1       10      11      19      18
CQUAD4  10      1       11      12      20      19
CQUAD4  11      1       12      13      21      20
CQUAD4  12      1       13      14      22      21
CQUAD4  13      1       14      15      23      22
CQUAD4  14      1       15      16      24      23
CQUAD4  15      1       17      18      26      25
CQUAD4  16      1       18      19      27      26
CQUAD4  17      1       19      20      28      27
CQUAD4  18      1       20      21      29      28
CQUAD4  19      1       21      22      30      29
CQUAD4  20      1       22      23      31      30
CQUAD4  21      1       23      24      32      31
CQUAD4  22      1       25      26      34      33                      +M00007
+M00007                  .041    .041    0.0     0.0
CQUAD4  23      1       26      27      35      34                      +M00008
+M00008                  .041    .041    0.0     0.0
CQUAD4  24      1       27      28      36      35                      +M00009
+M00009                  .041    .041    0.0     0.0
CQUAD4  25      1       28      29      37      36                      +M00010
+M00010                  .041    .041    0.0     0.0
CQUAD4  26      1       29      30      38      37                      +M00011
+M00011                  .041    .041    0.0     0.0
CQUAD4  27      1       30      31      39      38                      +M00012
+M00012                  .041    .041    0.0     0.0
CQUAD4  28      1       31      32      40      39                      +M00013
+M00013                  .041    .041    0.0     0.0
$                                                                       $
$        THE PSHELL ENTRY DEFINES THE MEMBRANE, BENDING, TRANSVERSE      $
$        SHEAR, AND COUPLING PROPERTIES OF THIN SHELL ELEMENTS.         $
$        IT LISTS ITS ID, MATERIAL ID ENTRIES 1,2 AND 3 FOR THE           $
$        MEMBRANE STIFFNESS PROPERTIES, DEFAULT VALUES OF THICKNESS     $
$        0.041, BENDING STIFFNESS AND TRANSVERSE SHEAR STIFFNESS AND    $
$        THE NON-STRUCTURAL MASS DEFAULTS TO ZERO.                      $
$                                                                       $
$       PID     MID1    T      MID2 12.*I/T**3  MID3    TS/T    NSM     $
PSHELL  1        1      .041     1               1
$                                                                       $
$                    * * PARAMETERS * *                                 $
$                                                                       $
$        THE PARAMETER WTMASS CONVERTS THE STRUCTURAL WEIGHT TO MASS    $
$        UNITS; ITS VALUE IS 1/G.                                       $
$                                                                       $
PARAM   WTMASS .0025901
$                                                                       $
$        COUPMASS (=1), CAUSES THE GENERATION OF CONSISTENT MASS        $
$        MATRICES RATHER THAN LUMPED MASS MATRICES.                     $
$                                                                       $
$       N       V1                                                      $
PARAM   COUPMASS  1
$                                                                       $
```

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Listing 7-11 Input Files for the 15-Degree Sweptback Wing

```
$ID MSC, HA144C
$$$$$$$$ HANDBOOK FOR AEROELASTIC ANALYSIS EXAMPLE HA144C       $$$$$$$$
$                                                                      $
$       MODEL DESCRIPTION       MODEL A OF NASA TN D-1824              $
$                               HALF SPAN 15 DEGREE SWEPT WING         $
$                               28 QUAD4 PANEL MODEL                   $
$                                                                      $
$                               THIS RUN ALSO DEMONSTRATES THAT THE    $
$                               USER MAY PROVIDE DOWNWASHES DUE TO     $
$                               INITIAL INCDENCE, TWIST, AND CAMBER    $
$                                                                      $
$       SOLUTION                WIND TUNNEL MOUNT, STATIC STABILITY    $
$                               ANALYSIS USING DOUBLET LATTICE METHOD  $
$                               AERODYNAMICS AT MACH NO. 0.45          $
$                                                                      $
$$$$$$$$                                                        $$$$$$$$
TIME 5 $ CPU TIME IN MINUTES
DIAG 8,15 $
SOL 144
CEND
TITLE = EXAMPLE HA144C: HALF SPAN 15-DEG SWEPT UNTAPERED WING  HA144C
SUBT  = CANTILEVERED WIND TUNNEL MOUNT, DOUBLET-LATTICE AERO
LABEL = 0.041 IN PLATE W/BEVELLED LEADING AND TRAILING EDGES
  ECHO   = BOTH
  LOAD   = 30 $ GRAVITY LOAD
  SPC    = 1
  DISP   = ALL
  STRESS = ALL
  FORCE  = ALL
  AEROF  = ALL
  APRES  = ALL
  GPFORCES = ALL
  MONITOR  = ALL
  TRIMF(APPLIED,AIR) = ALL
SUBCASE 1
  TRIM = 1
SUBCASE 2
  TRIM = 2
BEGIN BULK
$*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
$                                                                       $
$        THE ANNOTATIONS IN THIS INPUT DECK ARE INTENDED TO             $
$        EXPLAIN THE DATA ON THE ENTRIES FOR THIS                       $
$        EXAMPLE WITHOUT REFERENCE TO THE VARIOUS MANUALS WHERE         $
$        MORE GENERAL DESCRIPTIONS WILL BE FOUND.                       $
$                                                                       $
$*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
INCLUDE 'PLATEST.DAT'
$                                                                       $
$        THE RBAR ENTRY DEFINES A RIGID BAR WITH SIX DEGREES OF         $
$        FREEDOM AT EACH END.  LISTED ARE THE GRID POINT NUMBERS,       $
$        THE INDEPENDENT AND THE DEPENDENT DOFS AT THE TWO ENDS.        $
$                                                                       $
$       EID     GA      GB      CNA     CNB     CMA     CMB             $
RBAR    101     17      9       123456
RBAR    102     17      25      123456
$                                                                       $
$                * * MASS AND INERTIA PROPERTIES * *                    $
$                                                                       $
$        THE MAT1 ENTRY DEFINES THE MATERIAL PROPERTIES FOR LINEAR,     $
$        TEMPERATURE-INDEPENDENT, ISOTROPIC MATERIALS.  IT LISTS        $
$        YOUNGS MODULUS, THE SHEAR MODULUS, POISSONS RATIO MASS         $
$        DENSITY, THERMAL EXPANSION COEFFICIENT AND STRUCTURAL          $
$        ELEMENT DAMPING.                                               $
$                                                                       $
$       MID     E       G       NU      RHO     A       TREF    GE
MAT1    1       10.3+6  3.9+6           0.1
$       SID     CID     G       N1      N2      N3
$                                                                       $
$        THE GRAV ENTRY DEFINES A UNIT GRAVITY VECTOR TO BE USED        $
$        TO APPLY THE GRAVITY LOAD.  LISTED ARE THE COORDINATE          $
$        SYSTEM, THE SCALAR ACCELERATION DUE TO GRAVITY AND THE         $
$        COMPONENTS OF THE UNIT VECTOR.                                 $
$                                                                       $
GRAV    10              386.088 0.0     0.0     -1.0
PARAMGRDPNT17
$                                                                       $
PARAM   AUNITS  .0025901
$       SID     S       S1      L1      S2      L2      ETC             $
LOAD    30      1.0     1.0     10
$                                                                       $
```

Listing 7-11 Input Files for the 15-Degree Sweptback Wing (Continued)

```
$                                                                      $
$                   * * STRUCTURAL CONSTRAINTS * *                     $
$                                                                      $
$        THE SPC1 ENTRY DEFINES SETS OF SINGLE-POINT CONSTRAINTS.      $
$        IT LISTS ITS ID, THE DOF COMPONENTS TO BE CONSTRAINED         $
$        AND THE GRID POINT NO.                                        $
$                                                                      $
$       SID     C       G1      G2      ETC.
SPC1    1       123456  17
SPC1    1       6       1       THRU    8
SPC1    1       6       10      THRU    16
SPC1    1       6       18      THRU    24
SPC1    1       6       26      THRU    40
$                                                                      $
$                   * * * AERODYNAMIC DATA * * *                       $
$                                                                      $
$                        (LB-IN-SEC SYSTEM)                            $
$                                                                      $
$                     * * ELEMENT GEOMETRY * *                         $
$                                                                      $
$        THE AEROS ENTRY IS UNIQUE TO THE STATIC AEROELASTICITY        $
$        SOLUTION, SOL21.  ACSID IDENTIFIES THE AERO COORDINATE        $
$        SYSTEM.  RCSID IDENTIFIES THE REFERENCE COORDINATE SYS-       $
$        TEM FOR RIGID BODY MOTION.  REFC IS THE REFERENCE CHORD.      $
$        REFB IS THE REFERENCE SPAN (NOT THE SEMI-SPAN).  REFS IS      $
$        THE REFERENCE WING AREA (FOR ONE SIDE ONLY, IN THIS CASE).    $
$        SYMXZ AND SYMXY ARE SYMMETRY KEYS THAT SPECIFY THE            $
$        PRESENCE OF REFLECTION PLANES ONLY, NOT THE EXISTENCE OF      $
$        OTHER LIFTING SURFACES.                                       $
$                                                                      $
$       ACSID   RCSID   REFC    REFB    REFS    SYMXZ   SYMXY
AEROS   0       11      2.07055 11.0502 11.4400 1
$                                                                      $
$        THIS CORD2R ENTRY DEFINES THE AERO COORDINATE SYSTEM          $
$        FLAGGED BY THE AEROS ENTRY.  THE ORIGIN IS AT THE WING        $
$        SUPPORT POINT (GRID 17).  LISTED ARE THE ORIGIN, A POINT      $
$        ON THE Z-AXIS AND A POINT ON THE X-AXIS, ALL IN THE RID       $
$        COORDINATE SYSTEM.                                            $
$                                                                      $
$       CID     RID     A1      A2      A3      B1      B2      B3
CORD2R  11              1.035275 0.0    0.0     1.035275 0.0    1.0     +CORD1
$       C1      C2      C3
+CORD1  2.0     0.0     0.0
$                                                                      $
$        THE CAERO1 ENTRY IS USED FOR DOUBLET LATTICE AERODYNAMICS.    $
$        LISTED ARE ITS PAERO ENTRY ID AND THE COORDINATE SYSTEM       $
$        FOR LOCATING THE INBOARD AND OUTBOARD LEADING EDGE POINTS     $
$        (1 AND 4).  NSPAN AND NCHORD, OR LSPAN AND LCHORD, ARE        $
$        USED TO PARTITION THE WING INTO AERODYNAMIC PANELS.           $
$        THE FORMER FOR UNIFORMLY SPACED PANELS AND THE LATTER         $
$        FOR NON-UNIFORMLY SPACED PANELS.  IGID IS THE ID OF ITS       $
$        ASSOCIATED INTERFERENCE GROUP.  THE CONTINUATION ENTRY        $
$        DEFINES POINTS 1 AND 4, THE ROOT CHORD AND TIP CHORD.         $
$        THE BOXES FORMED BY THE GRID LINES WILL BE NUMBERED           $
$        BEGINNING WITH EID SO CHOOSE A NUMBER THAT IS UNIQUE,         $
$        AND IS GREATER THAN ALL STRUCTURAL GRID, SCALAR AND           $
$        EXTRA POINT IDS.                                              $
$       EID     PID     CP      NSPAN   NCHORD  LSPAN   LCHORD  IGID
CAERO1  101     1       0       6       4                       1       +CA101
$      ( FWD LEFT POINT  )    ROOTCHORD ( FWD RIGHT POINT  )  TIP CHORD
$       X1      Y1      Z1      X12     X4      Y4      Z4      X14
+CA101  .0      .0      .0      2.07055 1.48044 5.52510 0.0     2.07055
$                                                                      $
$        THE PAERO1 ENTRY IS REQUIRED EVEN THOUGH IT IS NON-FUNCTIONAL $
$        (BECAUSE THERE ARE NO ASSOCIATED BODIES IN THIS EXAMPLE).     $
$                                                                      $
$       PID     B1      B2      B3      B4      B5      B6
PAERO1  1
$
$                 * SURFACE SPLINE FIT ON THE WING *                   $
$                                                                      $
$        THE SPLINE1 ENTRY DEFINES A SURFACE SPLINE FOR INTERPO-       $
$        LATING OUT-OF-PLANE DISPLACEMENTS FROM THE STRUCTURAL         $
$        GRID POINTS ON THE SETG ENTRY TO THE SUB-REGION DEFINED       $
$        BY AERODYNAMIC BOXES 101 THRU 124 OF THE REGION ON THE        $
$        CAERO1 ENTRY.  DZ=0 SPECIFIES THAT NO SMOOTHING OF THE        $
$        SPLINE IS TO BE IMPOSED.                                      $
$                                                                      $
$       EID     CAERO   BOX1    BOX2    SETG    DZ
SPLINE1 100     101     101     124     100     .0
$                                                                      $
$        THE SET1 ENTRY DEFINES THE STRUCTURAL GRID POINTS TO          $
$        BE USED BY THE SURFACE SPLINE FOR INTERPOLATION.              $
$                                                                      $
```

Main Index

Listing 7-11 Input Files for the 15-Degree Sweptback Wing (Continued)

```
$       SID     G1      G2      G3      G4      G5      G6
SET1    100     2       4       6       8       11      13      15
        18      20      22      24      27      29      31      34
        36      38      40
$                                                                       $
$                   * * USER SUPPLIED AERO DATA * *                     $
$                                                                       $
$        THE DMIJ ENTRY ACCOMMODATES DIRECT INPUT OF USER SUPPLIED      $
$        DOWNWASH VECTOR. LISTED ARE THE NAME OF THE MATRIX, THE        $
$        FORM OF MATRIX, THE TYPE OF DATA BEING INPUT, AND THE TYPE     $
$        EXPECTED AS OUTPUT.  ONLY ONE COLUMN IS INPUT FOR ALL TRIM     $
$        CASES.
$                                                                       $
$     * INITIAL DOWNWASH (E.G., DUE TO INCIDENCE,TWIST OR CAMBER) *     $
$                                                                       $
DMIJ    W2GJ    0       9       1       0                       1
DMIJ    W2GJ    1       1       10130.17453
        102     3       0.17453         103     3       0.17453
        104     3       0.17453         105     3       0.17453
        106     3       0.17453         107     3       0.17453
        108     3       0.17453         109     3       0.17453
        110     3       0.17453         111     3       0.17453
        112     3       0.17453         113     3       0.17453
        114     3       0.17453         115     3       0.17453
        116     3       0.17453         117     3       0.17453
        118     3       0.17453         119     3       0.17453
        120     3       0.17453         121     3       0.17453
        122     3       0.17453         123     3       0.17453
        124     3       0.17453
$                                                                       $
$               * * * STATIC AEROELASTIC SOLUTION * * *                 $
$                                                                       $
$                       * * AERODYNAMIC DOFS * *                        $
$                                                                       $
$        THE AESTAT ENTRY LISTS TRIM VARIABLES USED TO SPECIFY          $
$        RIGID BODY MOTIONS.  THESE AND THE CONTROL SURFACE             $
$        ROTATIONS MAKE UP THE VARIABLES IN THE EQUATIONS OF            $
$        MOTION.                                                        $
$                                                                       $
AESTAT  501     ANGLEA
AESTAT  502     PITCH
AESTAT  503     URDD3
AESTAT  504     URDD5
$                                                                       $
$                       * * TRIM CONDITIONS * *                         $
$                                                                       $
$        THE TRIM ENTRY SPECIFIES CONSTRAINTS FOR THE TRIM VARIABLES    $
$        LISTED ON THE AESTAT AND AESURF ENTRIES.  LISTED ARE ITS ID,   $
$        THE MACH NUMBER, DYNAMIC PRESSURE AND PAIRS OF TRIM VARI-      $
$        ABLES AND THEIR CONSTRAINED VALUES.  IN THIS CASE, ALL FOUR    $
$      TRIM VALUES ARE 0.0                                $
$
$                                                                       $
TRIM    1       0.45    2.0     ANGLEA  0.0     PITCH   0.0
URDD30.0URDD50.0
TRIM    2       0.45    4.0     ANGLEA  0.0     PITCH   0.0
URDD30.0URDD50.0

$                                                                       $
$                       * * MONITOR POINTS  * *                         $
$                                                                       $
$       A SERIES OR MONPNT3'S PROVIDES CUTS AT DIFFERENT POINTS ALONG   $
$       THE SPAN OF THE MODEL                                           $
MONPNT3OUTBDALAST THREE ROWS OF ELEMENTS W/O THE LOADS ON THE CUT
12345650601.881243.15720.
MONPNT3OUTBDCONTAINS THE LAST THREE ROWS OF ELEMENTS
12345650601.881243.15720.SMAD
SET150513212937
SET1605121926
MONPNT3INBDCONTAINS THE LAST SIX ROWS OF ELEMENTS
12345615      16              1.24677 0.7893SMAD
SET115210182634
SET116291623
MONPNT3ROOT CONTAINS ALL THE ROWS OF ELEMENTS
12345625      26              1.03258 0.0     SMAD
SET12519172533
SET126181522
MONSUM  ROOTMA MODIFICATION OF ROOT
MONPNT3 123456ROOT    123     1.0     ROOT    456      12.
ENDDATA
```

Listing 7-12 Output for the 15-Degree Sweptback Wing

```
N O N - D I M E N S I O N A L   S T A B I L I T Y   A N D   C O N T R O L   D E R I V A T I V E   C O E F F I C I E N T S

                     CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
                                     MACH = 4.5000E-01                       Q = 2.0000E+00
                     CHORD = 2.0705E+00           SPAN = 1.1050E+01            AREA = 1.1440E+01

            TRANSFORMATION FROM BASIC TO REFERENCE COORDINATES:

          { X }        [  1.0000   0.0000   0.0000  ]  { X }        {-1.0353E+00 }
          { Y }    =   [  0.0000   1.0000   0.0000  ]  { Y }     +  { 0.0000E+00 }
          { Z }REF     [  0.0000   0.0000   1.0000  ]  { Z }BAS     { 0.0000E+00 }


CONTROLLER STATE: INTERCEPT ONLY, ALL CONTROLLERS ARE ZERO

TRIM VARIABLE   COEFFICIENT            RIGID                          ELASTIC                             INERTIAL
                               UNSPLINED        SPLINED        RESTRAINED      UNRESTRAINED      RESTRAINED       UNRESTRAINED

REF. COEFF.      CX          0.000000E+00    0.000000E+00    0.000000E+00         N/A          0.000000E+00         N/A
                 CY          0.000000E+00    0.000000E+00    0.000000E+00         N/A          0.000000E+00         N/A
                 CZ          7.829187E-01    7.829187E-01    6.799355E-01         N/A          0.000000E+00         N/A
                 CMX         0.000000E+00    0.000000E+00    0.000000E+00         N/A          0.000000E+00         N/A
                 CMY        -5.442816E-02   -5.442816E-02   -5.507554E-02         N/A          0.000000E+00         N/A
                 CMZ         0.000000E+00    0.000000E+00    0.000000E+00         N/A          0.000000E+00         N/A

ANGLEA           CX          0.000000E+00    0.000000E+00    0.000000E+00         N/A          0.000000E+00         N/A
                 CY          0.000000E+00    0.000000E+00    0.000000E+00         N/A          0.000000E+00         N/A
                 CZ          4.485869E+00    4.485869E+00    3.895809E+00         N/A          0.000000E+00         N/A
                 CMX         0.000000E+00    0.000000E+00    0.000000E+00         N/A          0.000000E+00         N/A
                 CMY        -3.118556E-01   -3.118556E-01   -3.155649E-01         N/A          0.000000E+00         N/A
                 CMZ         0.000000E+00    0.000000E+00    0.000000E+00         N/A          0.000000E+00         N/A

PITCH            CX          0.000000E+00    0.000000E+00    0.000000E+00         N/A          0.000000E+00         N/A
                 CY          0.000000E+00    0.000000E+00    0.000000E+00         N/A          0.000000E+00         N/A
                 CZ          5.203553E+00    5.203553E+00    2.853653E+00         N/A          0.000000E+00         N/A
                 CMX         0.000000E+00    0.000000E+00    0.000000E+00         N/A          0.000000E+00         N/A
                 CMY        -1.346726E+00   -1.346726E+00   -1.117084E+00         N/A          0.000000E+00         N/A
                 CMZ         0.000000E+00    0.000000E+00    0.000000E+00         N/A          0.000000E+00         N/A

URDD3            CX          0.000000E+00    0.000000E+00    0.000000E+00         N/A          0.000000E+00         N/A
                 CY          0.000000E+00    0.000000E+00    0.000000E+00         N/A          0.000000E+00         N/A
                 CZ          0.000000E+00    0.000000E+00    0.000000E+00         N/A          0.000000E+00         N/A
                 CMX         0.000000E+00    0.000000E+00    0.000000E+00         N/A          0.000000E+00         N/A
                 CMY         0.000000E+00    0.000000E+00    0.000000E+00         N/A          0.000000E+00         N/A
                 CMZ         0.000000E+00    0.000000E+00    0.000000E+00         N/A          0.000000E+00         N/A

URDD5            CX          0.000000E+00    0.000000E+00    0.000000E+00         N/A          0.000000E+00         N/A
                 CY          0.000000E+00    0.000000E+00    0.000000E+00         N/A          0.000000E+00         N/A
                 CZ          0.000000E+00    0.000000E+00    0.000000E+00         N/A          0.000000E+00         N/A
                 CMX         0.000000E+00    0.000000E+00    0.000000E+00         N/A          0.000000E+00         N/A
                 CMY         0.000000E+00    0.000000E+00    0.000000E+00         N/A          0.000000E+00         N/A
                 CMZ         0.000000E+00    0.000000E+00    0.000000E+00         N/A          0.000000E+00         N/A
                                              INTERMEDIATE MATRIX ... UX

                                                        COLUMN      1
 1               1.000000E+00       0.000000E+00       0.000000E+00       0.000000E+00       0.000000E+00                 5
                                              INTERMEDIATE MATRIX ... UXIFV

                                                        COLUMN      1
 1               1.000000E+00       0.000000E+00       0.000000E+00       0.000000E+00       0.000000E+00                 5

                           A E R O S T A T I C   D A T A   R E C O V E R Y   O U T P U T   T A B L E S
                     CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
                                       MACH = 4.500000E-01                     Q = 2.000000E+00
                     CHORD = 2.0705E+00           SPAN = 1.1050E+01            AREA = 1.1440E+01

      TRIM ALGORITHM USED: LINEAR TRIM SOLUTION WITHOUT REDUNDANT CONTROL SURFACES.
```

Listing 7-12 Output for the 15-Degree Sweptback Wing (Continued)

```
                                    AEROELASTIC TRIM VARIABLES

                       ID     LABEL                TYPE        TRIM STATUS      VALUE OF UX

                              INTERCEPT          RIGID BODY          FIXED      1.000000E+00
                      501     ANGLEA             RIGID BODY          FIXED      0.000000E+00  RADIANS
                      502     PITCH              RIGID BODY          FIXED      0.000000E+00  NONDIMEN. RATE
                      503     URDD3              RIGID BODY          FIXED      0.000000E+00  LOAD FACTOR
                      504     URDD5              RIGID BODY          FIXED      0.000000E+00  RAD/S/S PER G

                    A E R O S T A T I C   D A T A   R E C O V E R Y   O U T P U T   T A B L E S
               CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
                                 MACH = 4.500000E-01               Q = 2.000000E+00
               CHORD = 2.0705E+00           SPAN = 1.1050E+01          AREA = 1.1440E+01


                                 TRANSFORMATION FROM REFERENCE TO WIND AXES:
                      ANGLE OF ATTACK   =  0.000000E+00 RADIANS (     0.000000 DEGREES)
                      ANGLE OF SIDESLIP =  0.000000E+00 RADIANS (     0.000000 DEGREES)

                            { X }          [  1.000000  0.000000  0.000000 ]  { X }
                            { Y }          [  0.000000  1.000000  0.000000 ]  { Y }
                            { Z }WIND =    [  0.000000  0.000000  1.000000 ]  { Z }REF

  STRUCTURAL  MONITOR POINT TOTAL VEHICLE COEFFICIENTS:
        AXIS         RIGID AIR  +  RESTRAINED INCR.  -  INERTIAL  +   RIGID-APPLIED + RESTRAINED INCR.  =  BALANCE
        ----         ---------     ----------------     --------      -------------   ----------------     -------
  BODY  CX          0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00
  WIND  CD          0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00

  BODY  CY          0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00
  WIND  CY-WIND     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00

  BODY  CZ          7.829187E-01    -1.029832E-01     0.000000E+00    -1.671736E-03     1.204027E-03     6.794678E-01
  WIND  CL          7.829187E-01    -1.029832E-01     0.000000E+00    -1.671736E-03     1.204027E-03     6.794678E-01

  BODY  CMX         1.818539E-01    -2.780597E-02     0.000000E+00    -4.484402E-04     3.261982E-04     1.539257E-01
  WIND  CM-ROLL     1.818539E-01    -2.780597E-02     0.000000E+00    -4.484402E-04     3.261982E-04     1.539257E-01

  BODY  CMY        -5.442816E-02    -6.473863E-04     0.000000E+00     6.412684E-04    -1.532428E-04    -5.458752E-02
  WIND  CM-PITCH   -5.442816E-02    -6.473863E-04     0.000000E+00     6.412684E-04    -1.532428E-04    -5.458752E-02

  BODY  CMZ         0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00
  WIND  CM-YAW      0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00


  AERODYNAMIC MONITOR POINT TOTAL VEHICLE COEFFICIENTS:
        AXIS         RIGID AIR  +  RESTRAINED INCR.  -  INERTIAL  +   RIGID-APPLIED + RESTRAINED INCR.  =  BALANCE
        ----         ---------     ----------------     --------      -------------   ----------------     -------
  BODY  CX          0.000000E+00     0.000000E+00         N/A              N/A          0.000000E+00     0.000000E+00
  WIND  CD          0.000000E+00     0.000000E+00         N/A              N/A          0.000000E+00     0.000000E+00

  BODY  CY          0.000000E+00     0.000000E+00         N/A              N/A          0.000000E+00     0.000000E+00
  WIND  CY-WIND     0.000000E+00     0.000000E+00         N/A              N/A          0.000000E+00     0.000000E+00

  BODY  CZ          7.829187E-01    -1.029832E-01         N/A              N/A          1.204027E-03     6.811395E-01
  WIND  CL          7.829187E-01    -1.029832E-01         N/A              N/A          1.204027E-03     6.811395E-01

  BODY  CMX         1.818539E-01    -2.780597E-02         N/A              N/A          3.261982E-04     1.543741E-01
  WIND  CM-ROLL     1.818539E-01    -2.780597E-02         N/A              N/A          3.261982E-04     1.543741E-01

  BODY  CMY        -5.442816E-02    -6.473863E-04         N/A              N/A         -1.532428E-04    -5.522878E-02
  WIND  CM-PITCH   -5.442816E-02    -6.473863E-04         N/A              N/A         -1.532428E-04    -5.522878E-02

  BODY  CMZ         0.000000E+00     0.000000E+00         N/A              N/A          0.000000E+00     0.000000E+00
  WIND  CM-YAW      0.000000E+00     0.000000E+00         N/A              N/A          0.000000E+00     0.000000E+00
                    A E R O S T A T I C   D A T A   R E C O V E R Y   O U T P U T   T A B L E S
               CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
                                 MACH = 4.500000E-01               Q = 2.000000E+00
               CHORD = 2.0705E+00           SPAN = 1.1050E+01          AREA = 1.1440E+01
```

Listing 7-12 Output for the 15-Degree Sweptback Wing (Continued)

```
                                    AERODYNAMIC PRESSURES ON THE AERODYNAMIC ELEMENTS

                                                      AERODYNAMIC PRES.       AERODYNAMIC
                                        GRID   LABEL         COEFFICIENTS          PRESSURES
                                          1     LS          1.589226E+00         3.178451E+00
                                          2     LS          7.298057E-01         1.459611E+00
                                          3     LS          5.757041E-01         1.151408E+00
                                          4     LS          3.395002E-01         6.790003E-01
                                          5     LS          1.664636E+00         3.329273E+00
                                          6     LS          6.151970E-01         1.230394E+00
                                          7     LS          5.508073E-01         1.101615E+00
                                          8     LS          2.900049E-01         5.800097E-01
                                          9     LS          1.517660E+00         3.035320E+00
                                         10     LS          6.528094E-01         1.305619E+00
                                         11     LS          5.476492E-01         1.095298E+00
                                         12     LS          2.376085E-01         4.752171E-01
                                         13     LS          1.486017E+00         2.972035E+00
                                         14     LS          6.492375E-01         1.298475E+00
                                         15     LS          4.032602E-01         8.065203E-01
                                         16     LS          1.987533E-01         3.975066E-01
                                         17     LS          1.405344E+00         2.810688E+00
                                         18     LS          5.697875E-01         1.139575E+00
                                         19     LS          3.300681E-01         6.601361E-01
                                         20     LS          1.499980E-01         2.999959E-01
                                         21     LS          1.161693E+00         2.323386E+00
                                         22     LS          4.073622E-01         8.147244E-01
                                         23     LS          1.950552E-01         3.901104E-01
                                         24     LS          8.016938E-02         1.603388E-01

     *** LABEL NOTATIONS:  LS = LIFTING SURFACE,   ZIB = Z INTERFERENCE BODY ELEMENT,  ZSB = Z SLENDER BODY ELEMENT,
                                                   YIB = Y INTERFERENCE BODY ELEMENT,  YSB = Y SLENDER BODY ELEMENT.

                        A E R O S T A T I C   D A T A   R E C O V E R Y   O U T P U T   T A B L E S
                    CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
                                  MACH = 4.500000E-01                Q = 2.000000E+00
                    CHORD = 2.0705E+00          SPAN = 1.1050E+01          AREA = 1.1440E+01


                                          AERODYNAMIC FORCES ON THE AERODYNAMIC ELEMENTS

  GROUP  GRID ID  LABEL        T1                 T2                 T3                 R1                 R2                 R3
     1      101    LS     0.000000E+00       0.000000E+00       1.515061E+00       0.000000E+00       1.960631E-01       0.000000E+00
     1      102    LS     0.000000E+00       0.000000E+00       6.957479E-01       0.000000E+00       9.003630E-02       0.000000E+00
     1      103    LS     0.000000E+00       0.000000E+00       5.488377E-01       0.000000E+00       7.102475E-02       0.000000E+00
     1      104    LS     0.000000E+00       0.000000E+00       3.236567E-01       0.000000E+00       4.188421E-02       0.000000E+00
     1      105    LS     0.000000E+00       0.000000E+00       1.586953E+00       0.000000E+00       2.053666E-01       0.000000E+00
     1      106    LS     0.000000E+00       0.000000E+00       5.864875E-01       0.000000E+00       7.589699E-02       0.000000E+00
     1      107    LS     0.000000E+00       0.000000E+00       5.251028E-01       0.000000E+00       6.795322E-02       0.000000E+00
     1      108    LS     0.000000E+00       0.000000E+00       2.764712E-01       0.000000E+00       3.577797E-02       0.000000E+00
     1      109    LS     0.000000E+00       0.000000E+00       1.446835E+00       0.000000E+00       1.872341E-01       0.000000E+00
     1      110    LS     0.000000E+00       0.000000E+00       6.223447E-01       0.000000E+00       8.053724E-02       0.000000E+00
     1      111    LS     0.000000E+00       0.000000E+00       5.220921E-01       0.000000E+00       6.756361E-02       0.000000E+00
     1      112    LS     0.000000E+00       0.000000E+00       2.265201E-01       0.000000E+00       2.931382E-02       0.000000E+00
     1      113    LS     0.000000E+00       0.000000E+00       1.416669E+00       0.000000E+00       1.833303E-01       0.000000E+00
     1      114    LS     0.000000E+00       0.000000E+00       6.189395E-01       0.000000E+00       8.009658E-02       0.000000E+00
     1      115    LS     0.000000E+00       0.000000E+00       3.844412E-01       0.000000E+00       4.975030E-02       0.000000E+00
     1      116    LS     0.000000E+00       0.000000E+00       1.894781E-01       0.000000E+00       2.452024E-02       0.000000E+00
     1      117    LS     0.000000E+00       0.000000E+00       1.339761E+00       0.000000E+00       1.733776E-01       0.000000E+00
     1      118    LS     0.000000E+00       0.000000E+00       5.431972E-01       0.000000E+00       7.029481E-02       0.000000E+00
     1      119    LS     0.000000E+00       0.000000E+00       3.146648E-01       0.000000E+00       4.072057E-02       0.000000E+00
     1      120    LS     0.000000E+00       0.000000E+00       1.429980E-01       0.000000E+00       1.850528E-02       0.000000E+00
     1      121    LS     0.000000E+00       0.000000E+00       1.107480E+00       0.000000E+00       1.433183E-01       0.000000E+00
     1      122    LS     0.000000E+00       0.000000E+00       3.883518E-01       0.000000E+00       5.025636E-02       0.000000E+00
     1      123    LS     0.000000E+00       0.000000E+00       1.859525E-01       0.000000E+00       2.406400E-02       0.000000E+00
     1      124    LS     0.000000E+00       0.000000E+00       7.642812E-02       0.000000E+00       9.890515E-03       0.000000E+00

     *** LABEL NOTATIONS:  LS = LIFTING SURFACE,   ZSB =  Z SLENDER BODY ELEMENT,  YSB =  Y SLENDER BODY ELEMENT,
                                                  ZYSB = ZY SLENDER BODY ELEMENT, EXTA = EXTERNAL AERO.

                       S T R U C T U R A L   M O N I T O R   P O I N T   I N T E G R A T E D   L O A D S
                    CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
                                  MACH = 4.500000E-01                Q = 2.000000E+00

   CONTROLLER STATE: INTERCEPT ONLY, ALL CONTROLLERS ARE ZERO

   MONITOR POINT NAME = AEROSG2D          COMPONENT =                      CLASS = COEFFICIENT
   LABEL = Full Vehicle Integrated Loads
    CP =       11          X =  0.00000E+00          Y =  0.00000E+00          Z =  0.00000E+00          CD =       11

     AXIS       RIGID AIR       ELASTIC REST.    RIGID APPLIED     REST. APPLIED
     ----     -------------     -------------    -------------     -------------
      CX      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00
      CY      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00
      CZ      1.791318E+01      1.555692E+01     -3.824932E-02     -1.070119E-02
      CMX     4.597787E+01      3.894772E+01     -1.133785E-01     -3.090628E-02
      CMY    -2.578489E+00     -2.609159E+00      3.037957E-02      2.311982E-02
      CMZ     0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00
```

Listing 7-12 Output for the 15-Degree Sweptback Wing (Continued)

```
                    A E R O D Y N A M I C   M O N I T O R   P O I N T   I N T E G R A T E D   L O A D S
               CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
                                 MACH = 4.500000E-01                Q = 2.000000E+00

CONTROLLER STATE: INTERCEPT ONLY, ALL CONTROLLERS ARE ZERO

MONITOR POINT NAME = AEROSG2D          COMPONENT =                    CLASS = COEFFICIENT
LABEL = Full Vehicle Integrated Loads
 CP =       11          X =  0.00000E+00          Y =  0.00000E+00          Z =  0.00000E+00          CD =       11

  AXIS      RIGID AIR       ELASTIC REST.   REST. APPLIED
  ----    -------------    -------------    -------------
   CX      0.000000E+00     0.000000E+00     0.000000E+00
   CY      0.000000E+00     0.000000E+00     0.000000E+00
   CZ      1.791318E+01     1.555692E+01     2.754813E-02
   CMX     4.597787E+01     3.894772E+01     8.247222E-02
   CMY    -2.578489E+00    -2.609159E+00    -7.259753E-03
   CMZ     0.000000E+00     0.000000E+00     0.000000E+00
          S T R U C T U R A L   F R E E   B O D Y   M O N I T O R   P O I N T   I N T E G R A T E D   L O A D S
               CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
                                 MACH = 4.500000E-01                Q = 2.000000E+00

CONTROLLER STATE: INTERCEPT ONLY, ALL CONTROLLERS ARE ZERO

MONITOR POINT NAME = INBD                                             CLASS = GENERAL
LABEL = CONTAINS THE LAST SIX ROWS OF ELEMENTS
 CP =        0          X =  1.24677E+00          Y =  7.89300E-01          Z =  0.00000E+00          CD =        0

  AXIS     ELASTIC REST.
  ----    -------------
   CX      0.000000E+00
   CY      0.000000E+00
   CZ      1.074425E+01
   CMX     2.661571E+01
   CMY    -1.271572E+00
   CMZ     0.000000E+00

MONITOR POINT NAME = OUTBD                                            CLASS = GENERAL
LABEL = CONTAINS THE LAST THREE ROWS OF ELEMENTS
 CP =        0          X =  1.88124E+00          Y =  3.15720E+00          Z =  0.00000E+00          CD =        0

  AXIS     ELASTIC REST.
  ----    -------------
   CX      0.000000E+00
   CY      0.000000E+00
   CZ      4.410935E+00
   CMX     5.681655E+00
   CMY     1.014392E+00
   CMZ     0.000000E+00

MONITOR POINT NAME = OUTBDA                                           CLASS = GENERAL
LABEL = LAST THREE ROWS OF ELEMENTS W/O THE LOADS ON THE CUT
 CP =        0          X =  1.88124E+00          Y =  3.15720E+00          Z =  0.00000E+00          CD =        0

  AXIS     ELASTIC REST.
  ----    -------------
   CX      0.000000E+00
   CY      0.000000E+00
   CZ      6.616270E+00
   CMX     5.681655E+00
   CMY     2.204922E+00
   CMZ     0.000000E+00

MONITOR POINT NAME = ROOT                                             CLASS = GENERAL
LABEL = CONTAINS ALL THE ROWS OF ELEMENTS
 CP =        0          X =  1.03258E+00          Y =  0.00000E+00          Z =  0.00000E+00          CD =        0

  AXIS     ELASTIC REST.
  ----    -------------
   CX      0.000000E+00
   CY      0.000000E+00
   CZ      1.553259E+01
   CMX     3.887558E+01
   CMY    -2.624269E+00
   CMZ     0.000000E+00
```

Listing 7-12 Output for the 15-Degree Sweptback Wing (Continued)

```
MONITOR POINT NAME = ROOTM                                    CLASS = GENERAL
LABEL = A MODIFICATION OF ROOT
  CP,X,Y,Z AND CD ARE NOT DEFINED FOR MONITOR RESULTS CREATED FROM A MONSUM

  AXIS     ELASTIC REST.
  ----    -------------
   CX      0.000000E+00
   CY      0.000000E+00
   CZ      1.553259E+01
   CMX     4.665070E+02
   CMY    -3.149123E+01
   CMZ     0.000000E+00

0     0.041 IN PLATE W/BEVELLED LEADING AND TRAILING EDGES                                   SUBCASE 1

                                     D I S P L A C E M E N T   V E C T O R

 POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
        1      G      0.0            0.0          -2.577692E-03   5.731876E-02  -1.781615E-02   0.0
        2      G      0.0            0.0           8.023683E-02   1.248992E-01  -4.331491E-02   0.0
        3      G      0.0            0.0           3.211483E-01   4.267515E-01  -1.081572E-01   0.0
        4      G      0.0            0.0           7.231052E-01   5.223770E-01  -7.910193E-02   0.0
        5      G      0.0            0.0           1.198894E+00   6.286718E-01  -7.042374E-02   0.0
        6      G      0.0            0.0           1.719264E+00   6.488008E-01  -4.359301E-02   0.0
        7      G      0.0            0.0           2.248496E+00   6.657318E-01  -3.705957E-02   0.0
        8      G      0.0            0.0           2.779271E+00   6.602428E-01  -2.755582E-02   0.0
        9      G      0.0            0.0           0.0            0.0            0.0            0.0
       10      G      0.0            0.0           8.826179E-02   1.972071E-01  -4.062480E-02   0.0
       11      G      0.0            0.0           3.460443E-01   4.087746E-01  -8.583405E-02   0.0
       12      G      0.0            0.0           7.418798E-01   5.407789E-01  -7.136835E-02   0.0
       13      G      0.0            0.0           1.215876E+00   6.167530E-01  -5.941465E-02   0.0
       14      G      0.0            0.0           1.729886E+00   6.525340E-01  -4.352726E-02   0.0
       15      G      0.0            0.0           2.257733E+00   6.611137E-01  -3.413437E-02   0.0
       16      G      0.0            0.0           2.786223E+00   6.605283E-01  -2.905224E-02   0.0
       17      G      0.0            0.0           0.0            0.0            0.0            0.0
       18      G      0.0            0.0           1.121740E-01   2.601277E-01  -2.274387E-02   0.0
       19      G      0.0            0.0           3.917523E-01   4.225165E-01  -3.184064E-02   0.0
       20      G      0.0            0.0           7.852870E-01   5.455448E-01  -3.993269E-02   0.0
       21      G      0.0            0.0           1.253840E+00   6.138299E-01  -3.791306E-02   0.0
       22      G      0.0            0.0           1.760558E+00   6.457911E-01  -3.516053E-02   0.0
       23      G      0.0            0.0           2.282746E+00   6.573977E-01  -3.024730E-02   0.0
       24      G      0.0            0.0           2.808917E+00   6.593395E-01  -2.941900E-02   0.0
       25      G      0.0            0.0           0.0            0.0            0.0            0.0
       26      G      0.0            0.0           1.126709E-01   2.770091E-01   2.371418E-02   0.0
       27      G      0.0            0.0           4.021721E-01   4.539541E-01   6.758590E-03   0.0
       28      G      0.0            0.0           8.068813E-01   5.604696E-01  -1.420625E-02   0.0
       29      G      0.0            0.0           1.278559E+00   6.176298E-01  -2.470098E-02   0.0
       30      G      0.0            0.0           1.785075E+00   6.475140E-01  -2.733510E-02   0.0
       31      G      0.0            0.0           2.306065E+00   6.551049E-01  -2.941148E-02   0.0
       32      G      0.0            0.0           2.830610E+00   6.586774E-01  -2.619480E-02   0.0
       33      G      0.0            0.0          -7.752810E-03   5.875676E-02   4.359974E-02   0.0
       34      G      0.0            0.0           1.065594E-01   2.546463E-01   3.750029E-02   0.0
       35      G      0.0            0.0           3.989374E-01   4.904224E-01   2.024683E-02   0.0
       36      G      0.0            0.0           8.103643E-01   5.482039E-01  -9.138996E-03   0.0
       37      G      0.0            0.0           1.284436E+00   6.370905E-01  -2.064923E-02   0.0
       38      G      0.0            0.0           1.792078E+00   6.333443E-01  -2.592395E-02   0.0
       39      G      0.0            0.0           2.313609E+00   6.709038E-01  -2.886274E-02   0.0
       40      G      0.0            0.0           2.837328E+00   6.406328E-01  -2.734971E-02   0.0

0     0.041 IN PLATE W/BEVELLED LEADING AND TRAILING EDGES                                   SUBCASE 1

                       F O R C E S   I N   Q U A D R I L A T E R A L   E L E M E N T S   ( Q U A D 4 )

 ELEMENT              - MEMBRANE  FORCES -                      - BENDING  MOMENTS -            - TRANSVERSE SHEAR FORCES -
   ID              FX            FY            FXY            MX            MY           MXY            QX            QY
     1      0.0           0.0           0.0          -2.512157E+00 -1.075614E-01  1.084806E-01  -4.098938E-01  1.522716E+00
     2      0.0           0.0           0.0          -4.908374E+00 -5.066718E-01 -4.421269E-02  -4.814690E-01  1.804255E+00
     3      0.0           0.0           0.0          -1.911023E+00  4.111530E-02  5.755779E-01  -3.034363E-01  8.160339E-01
     4      0.0           0.0           0.0          -1.587187E+00 -6.476180E-02  3.361220E-01  -2.151598E-01  5.389515E-01
     5      0.0           0.0           0.0          -4.067662E-01  9.336810E-03  3.418284E-01  -1.593471E-01  4.277289E-01
     6      0.0           0.0           0.0          -2.029838E-02 -3.295927E-02  1.086124E-01  -1.100183E-01  3.913117E-01
     7      0.0           0.0           0.0           8.517745E-02  9.840560E-03  8.687493E-02  -4.429301E-02  1.887335E-01
     8      0.0           0.0           0.0          -1.840645E+01 -4.868396E+00 -3.601107E-02  -1.000518E+01  2.058985E+00
     9      0.0           0.0           0.0          -1.412606E+01 -1.316911E+00 -4.282448E-01  -7.312887E+00  1.644269E+00
    10      0.0           0.0           0.0          -9.236015E+00  2.381389E-01  8.124159E-01  -6.252949E+00  7.273049E-01
    11      0.0           0.0           0.0          -5.186914E+00  2.263817E-01  7.308486E-01  -4.549806E+00  3.444922E-01
    12      0.0           0.0           0.0          -2.400416E+00  1.936684E-01  6.664004E-01  -3.028124E+00  1.845639E-01
    13      0.0           0.0           0.0          -6.929564E-01  1.095423E-01  4.319221E-01  -1.613276E+00  1.143164E-01
    14      0.0           0.0           0.0          -2.283639E-02  7.170673E-02  1.598936E-01  -3.239796E-01  3.645135E-02
    15      0.0           0.0           0.0          -2.141040E+01 -5.355080E+00  1.843773E+00  -9.630483E+00  6.611787E-01
    16      0.0           0.0           0.0          -1.262392E+01 -5.962195E-01  2.498206E-01  -6.322370E+00 -4.100209E-01
    17      0.0           0.0           0.0          -8.394773E+00  3.796790E-02 -1.899400E-01  -5.475707E+00 -2.783214E-01
    18      0.0           0.0           0.0          -4.557891E+00  1.037447E-01  9.679026E-02  -3.945663E+00 -2.691152E-01
    19      0.0           0.0           0.0          -2.233478E+00  8.502686E-02  1.621370E-01  -2.634014E+00 -1.853976E-01
```

Listing 7-12 Output for the 15-Degree Sweptback Wing (Continued)

```
        20       0.0           0.0           0.0          -6.712611E-01  8.951754E-02  1.231041E-01   -1.365484E+00 -1.545221E-01
        21       0.0           0.0           0.0          -1.801467E-01  5.925605E-02  1.214649E-01   -2.663997E-01 -1.843017E-01
        22       0.0           0.0           0.0          -4.024872E+00  3.276050E-01  5.657756E-01   -1.271187E-01  3.058114E-01
        23       0.0           0.0           0.0          -3.880665E+00 -5.041093E-01  4.760694E-01   -4.627003E-03 -6.527826E-01
        24       0.0           0.0           0.0          -1.466917E+00  2.545379E-01 -1.111079E-01   -6.553796E-02 -1.188633E-01
        25       0.0           0.0           0.0          -1.387594E+00 -1.615641E-01  1.118963E-01   -7.445452E-02 -2.107240E-02
        26       0.0           0.0           0.0          -2.032261E-01  1.321515E-01 -2.709856E-02   -5.045674E-02  4.870988E-02
        27       0.0           0.0           0.0          -4.366537E-01 -8.510863E-02  4.467524E-02   -2.844245E-02  1.326635E-02
        28       0.0           0.0           0.0           2.625038E-01  5.482191E-02 -5.505892E-03   -2.347876E-02  1.070704E-01

0     0.041 IN PLATE W/BEVELLED LEADING AND TRAILING EDGES                                                      SUBCASE 1

                             S T R E S S E S   I N   Q U A D R I L A T E R A L   E L E M E N T S   ( Q U A D 4 )
  ELEMENT        FIBER             STRESSES IN ELEMENT COORD SYSTEM             PRINCIPAL STRESSES (ZERO SHEAR)
    ID.        DISTANCE          NORMAL-X       NORMAL-Y      SHEAR-XY      ANGLE         MAJOR           MINOR         VON MISES
0       1   -1.025000E-02    -1.793331E+04 -7.678386E+02  7.744007E+02   87.4221   -7.329732E+02   -1.796817E+04   1.761313E+04
             1.025000E-02     1.793331E+04  7.678386E+02 -7.744007E+02   -2.5779    1.796817E+04    7.329732E+02   1.761313E+04
0       2   -1.025000E-02    -3.503896E+04 -3.616931E+03 -3.156170E+02  -89.4246   -3.613761E+03   -3.504213E+04   3.338227E+04
             1.025000E-02     3.503896E+04  3.616931E+03  3.156170E+02    0.5754    3.504213E+04    3.613761E+03   3.338227E+04
0       3   -1.025000E-02    -1.364204E+04  2.935060E+02  4.108825E+03   74.7363    1.414756E+03   -1.476330E+04   1.551911E+04
             1.025000E-02     1.364204E+04 -2.935060E+02 -4.108825E+03  -15.2637    1.476330E+04   -1.414756E+03   1.551911E+04
0       4   -1.025000E-02    -1.133030E+04 -4.623091E+02  2.399443E+03   78.0878    4.386650E+01   -1.183648E+04   1.185847E+04
             1.025000E-02     1.133030E+04  4.623091E+02 -2.399443E+03  -11.9122    1.183648E+04   -4.386650E+01   1.185847E+04
0       5   -1.025000E-02    -2.903745E+03  6.665183E+01  2.440179E+03   60.6633    1.438075E+03   -4.275168E+03   5.147148E+03
             1.025000E-02     2.903745E+03 -6.665183E+01 -2.440179E+03  -29.3367    4.275168E+03   -1.438075E+03   5.147148E+03
0       6   -1.025000E-02    -1.449022E+03 -2.352833E+02  7.753411E+02   64.0254    1.424510E+02   -1.826756E+03   1.901987E+03
             1.025000E-02     1.449022E+03  2.352833E+02 -7.753411E+02  -25.9746    1.826756E+03   -1.424510E+02   1.901987E+03
0       7   -1.025000E-02     6.080485E+02  7.024790E+01  6.201661E+02   33.2794    1.015102E+03   -3.368054E+02   1.218918E+03
             1.025000E-02    -6.080485E+02 -7.024790E+01 -6.201661E+02  -56.7206    3.368054E+02   -1.015102E+03   1.218918E+03
0       8   -2.050000E-02    -6.569823E+04 -1.737679E+04 -1.285345E+02  -89.8476   -1.737644E+04   -6.569857E+04   5.896300E+04
             2.050000E-02     6.569823E+04  1.737679E+04  1.285345E+02    0.1524    6.569857E+04    1.737644E+04   5.896300E+04
0       9   -2.050000E-02    -5.042022E+04 -4.700457E+03 -1.528536E+03  -88.0873   -4.649411E+03   -5.047126E+04   4.831463E+04
             2.050000E-02     5.042022E+04  4.700457E+03  1.528536E+03    1.9127    5.047126E+04    4.649411E+03   4.831463E+04
0      10   -2.050000E-02    -3.296614E+04  8.499903E+02  2.899759E+03   85.1342    1.096845E+03   -3.321300E+04   3.377478E+04
             2.050000E-02     3.296614E+04 -8.499903E+02 -2.899759E+03   -4.8658    3.321300E+04   -1.096845E+03   3.377478E+04
0      11   -2.050000E-02    -1.851367E+04  8.080251E+02  2.608621E+03   82.4447    1.154019E+03   -1.885967E+04   1.946235E+04
             2.050000E-02     1.851367E+04 -8.080251E+02 -2.608621E+03   -7.5553    1.885967E+04   -1.154019E+03   1.946235E+04
0      12   -2.050000E-02    -8.567816E+03  6.912613E+02  2.378586E+03   76.4033    1.266557E+03   -9.143111E+03   9.837729E+03
             2.050000E-02     8.567816E+03 -6.912613E+02 -2.378586E+03  -13.5967    9.143111E+03   -1.266557E+03   9.837729E+03
0      13   -2.050000E-02    -2.473372E+03  3.909896E+02  1.541661E+03   66.4458    1.063057E+03   -3.145440E+03   3.790470E+03
             2.050000E-02     2.473372E+03 -3.909896E+02 -1.541661E+03  -23.5542    3.145440E+03   -1.063057E+03   3.790470E+03
0      14   -2.050000E-02    -8.151001E+01  2.559431E+02  5.707088E+02   53.2350    6.823445E+02   -5.079114E+02   1.034475E+03
             2.050000E-02     8.151001E+01 -2.559431E+02 -5.707088E+02  -36.7650    5.079114E+02   -6.823445E+02   1.034475E+03
0      15   -2.050000E-02    -7.642022E+04 -1.911391E+04  6.580985E+03   83.5324   -1.836787E+04   -7.716626E+04   6.981856E+04
             2.050000E-02     7.642022E+04  1.911391E+04 -6.580985E+03   -6.4676    7.716626E+04    1.836787E+04   6.981856E+04
0      16   -2.050000E-02    -4.505862E+04 -2.128089E+03  8.916857E+02   88.8106   -2.109576E+03   -4.507713E+04   4.406024E+04
             2.050000E-02     4.505862E+04  2.128089E+03 -8.916857E+02   -1.1894    4.507713E+04    2.109576E+03   4.406024E+04
0      17   -2.050000E-02    -2.996350E+04  1.355190E+02 -6.779537E+02  -88.7103    1.507816E+02   -2.997876E+04   3.005443E+04
             2.050000E-02     2.996350E+04 -1.355190E+02  6.779537E+02    1.2897    2.997876E+04   -1.507816E+02   3.005443E+04
0      18   -2.050000E-02    -1.626850E+04  3.702964E+02  3.454739E+02   88.8110    3.774665E+02   -1.627567E+04   1.646765E+04
             2.050000E-02     1.626850E+04 -3.702964E+02 -3.454739E+02   -1.1890    1.627567E+04   -3.774665E+02   1.646765E+04
0      19   -2.050000E-02    -7.971964E+03  3.034867E+02  5.787164E+02   86.0190    3.437613E+02   -8.012238E+03   8.189532E+03
             2.050000E-02     7.971964E+03 -3.034867E+02 -5.787164E+02   -3.9810    8.012238E+03   -3.437613E+02   8.189532E+03
0      20   -2.050000E-02    -2.395935E+03  3.195153E+02  4.393961E+02   81.0335    3.888454E+02   -2.465265E+03   2.680921E+03
             2.050000E-02     2.395935E+03 -3.195153E+02 -4.393961E+02   -8.9665    2.465265E+03   -3.888454E+02   2.680921E+03
0      21   -2.050000E-02    -6.429983E+02  2.115029E+02  4.335453E+02   67.2905    3.929431E+02   -8.244386E+02   1.076132E+03
             2.050000E-02     6.429983E+02 -2.115029E+02 -4.335453E+02  -22.7095    8.244386E+02   -3.929431E+02   1.076132E+03
0      22   -1.025000E-02    -2.873198E+04  2.338644E+03  4.038850E+03   82.7135    2.855068E+03   -2.924841E+04   3.077543E+04
             1.025000E-02     2.873198E+04 -2.338644E+03 -4.038850E+03   -7.2865    2.924841E+04   -2.855068E+03   3.077543E+04
0      23   -1.025000E-02    -2.770255E+04 -3.598639E+03  3.398473E+03   82.1262   -3.128643E+03   -2.817254E+04   2.674582E+04
             1.025000E-02     2.770255E+04  3.598639E+03 -3.398473E+03   -7.8738    2.817254E+04    3.128643E+03   2.674582E+04
0      24   -1.025000E-02    -1.047174E+04  1.817046E+03 -7.931555E+02  -86.3223    1.868027E+03   -1.052272E+04   1.157039E+04
             1.025000E-02     1.047174E+04 -1.817046E+03  7.931555E+02    3.6777    1.052272E+04   -1.868027E+03   1.157039E+04
0      25   -1.025000E-02    -9.905488E+03 -1.153343E+03  7.987841E+02   84.8277   -1.081037E+03   -9.977794E+03   9.483599E+03
             1.025000E-02     9.905488E+03  1.153343E+03 -7.987841E+02   -5.1723    9.977794E+03    1.081037E+03   9.483599E+03
0      26   -1.025000E-02    -1.450752E+03  9.433780E+02 -1.934460E+02  -85.4102    9.589077E+02   -1.466281E+03   2.115541E+03
             1.025000E-02     1.450752E+03 -9.433780E+02  1.934460E+02    4.5898    1.466281E+03   -9.589077E+02   2.115541E+03
0      27   -1.025000E-02    -3.117100E+03 -6.075572E+02  3.189190E+02   82.8697   -5.676623E+02   -3.156994E+03   2.914918E+03
             1.025000E-02     3.117100E+03  6.075572E+02 -3.189190E+02   -7.1303    3.156994E+03    5.676623E+02   2.914918E+03
0      28   -1.025000E-02     1.873911E+03  3.913521E+02 -3.930441E+01   -1.5176    1.874953E+03    3.903108E+02   1.713469E+03
             1.025000E-02    -1.873911E+03 -3.913521E+02  3.930441E+01   88.4824   -3.903108E+02   -1.874953E+03   1.713469E+03
```

Listing 7-13 Trimmed Loads for the 15-Degree Sweptback Wing

```
$.......................................................................
$
$ TRIM CASE: 1
$ ELASTIC APPLIED LOADS
$
FORCE          1       1       0   1.0     0.0     0.0  -6.980-5
FORCE          1       2       0   1.0     0.0     0.0   .002043
FORCE          1       3       0   1.0     0.0     0.0  -1.396-4
FORCE          1       4       0   1.0     0.0     0.0   .001999
FORCE          1       5       0   1.0     0.0     0.0  -1.396-4
FORCE          1       6       0   1.0     0.0     0.0   .00249
FORCE          1       7       0   1.0     0.0     0.0  -1.396-4
FORCE          1       8       0   1.0     0.0     0.0   7.963-4
FORCE          1       9       0   1.0     0.0     0.0  -7.678-4
FORCE          1      10       0   1.0     0.0     0.0  -.001536
FORCE          1      11       0   1.0     0.0     0.0   6.613-4
FORCE          1      12       0   1.0     0.0     0.0  -.001536
FORCE          1      13       0   1.0     0.0     0.0   .002555
FORCE          1      14       0   1.0     0.0     0.0  -.001536
FORCE          1      15       0   1.0     0.0     0.0   .002571
FORCE          1      16       0   1.0     0.0     0.0  -7.678-4
FORCE          1      17       0   1.0     0.0     0.0  -.001256
FORCE          1      18       0   1.0     0.0     0.0  -3.400-4
FORCE          1      19       0   1.0     0.0     0.0  -.002513
FORCE          1      20       0   1.0     0.0     0.0  -1.481-4
FORCE          1      21       0   1.0     0.0     0.0  -.002513
FORCE          1      22       0   1.0     0.0     0.0  -5.585-5
FORCE          1      23       0   1.0     0.0     0.0  -.002513
FORCE          1      24       0   1.0     0.0     0.0  -6.050-4
FORCE          1      25       0   1.0     0.0     0.0  -7.678-4
FORCE          1      26       0   1.0     0.0     0.0  -.001536
FORCE          1      27       0   1.0     0.0     0.0  -.001124
FORCE          1      28       0   1.0     0.0     0.0  -.001536
FORCE          1      29       0   1.0     0.0     0.0  -8.945-4
FORCE          1      30       0   1.0     0.0     0.0  -.001536
FORCE          1      31       0   1.0     0.0     0.0  -9.427-4
FORCE          1      32       0   1.0     0.0     0.0  -7.678-4
FORCE          1      33       0   1.0     0.0     0.0  -6.980-5
FORCE          1      34       0   1.0     0.0     0.0   2.846-4
FORCE          1      35       0   1.0     0.0     0.0  -1.396-4
FORCE          1      36       0   1.0     0.0     0.0  -1.926-4
FORCE          1      37       0   1.0     0.0     0.0  -1.396-4
FORCE          1      38       0   1.0     0.0     0.0  -2.589-4
FORCE          1      39       0   1.0     0.0     0.0  -1.396-4
FORCE          1      40       0   1.0     0.0     0.0  -2.762-4
$.......................................................................
$
$ TRIM CASE: 1
$ ELASTIC AERODYNAMIC LOADS
$
FORCE          2       2       0   1.0     0.0     0.0   2.3305
FORCE          2       4       0   1.0     0.0     0.0   1.11722
FORCE          2       6       0   1.0     0.0     0.0   1.01866
FORCE          2       8       0   1.0     0.0     0.0   .280352
FORCE          2      11       0   1.0     0.0     0.0   1.40309
FORCE          2      13       0   1.0     0.0     0.0   1.87019
FORCE          2      15       0   1.0     0.0     0.0   1.59311
FORCE          2      18       0   1.0     0.0     0.0   2.03688
FORCE          2      20       0   1.0     0.0     0.0   1.45862
FORCE          2      22       0   1.0     0.0     0.0   1.12717
FORCE          2      24       0   1.0     0.0     0.0   .28518
FORCE          2      27       0   1.0     0.0     0.0   .183931
FORCE          2      29       0   1.0     0.0     0.0   .338639
FORCE          2      31       0   1.0     0.0     0.0   .275667
FORCE          2      34       0   1.0     0.0     0.0   .424432
FORCE          2      36       0   1.0     0.0     0.0  -.026684
FORCE          2      38       0   1.0     0.0     0.0  -.057848
FORCE          2      40       0   1.0     0.0     0.0  -.102184
$.......................................................................
```

Listing 7-13 Trimmed Loads for the 15-Degree Sweptback Wing

```
$
$ TRIM CASE: 1
$ ELASTIC (AERODYNAMIC + APPLIED - INERTIAL) LOADS
$
FORCE          3       1       0   1.0     0.0     0.0  -6.980-5
FORCE          3       2       0   1.0     0.0     0.0   2.33254
FORCE          3       3       0   1.0     0.0     0.0  -1.396-4
FORCE          3       4       0   1.0     0.0     0.0   1.11922
FORCE          3       5       0   1.0     0.0     0.0  -1.396-4
FORCE          3       6       0   1.0     0.0     0.0   1.02115
FORCE          3       7       0   1.0     0.0     0.0  -1.396-4
FORCE          3       8       0   1.0     0.0     0.0   .281148
FORCE          3       9       0   1.0     0.0     0.0  -7.678-4
FORCE          3      10       0   1.0     0.0     0.0  -.001536
FORCE          3      11       0   1.0     0.0     0.0   1.40375
FORCE          3      12       0   1.0     0.0     0.0  -.001536
FORCE          3      13       0   1.0     0.0     0.0   1.87275
FORCE          3      14       0   1.0     0.0     0.0  -.001536
FORCE          3      15       0   1.0     0.0     0.0   1.59569
FORCE          3      16       0   1.0     0.0     0.0  -7.678-4
FORCE          3      17       0   1.0     0.0     0.0  -.001256
FORCE          3      18       0   1.0     0.0     0.0   2.03654
FORCE          3      19       0   1.0     0.0     0.0  -.002513
FORCE          3      20       0   1.0     0.0     0.0   1.45847
FORCE          3      21       0   1.0     0.0     0.0  -.002513
FORCE          3      22       0   1.0     0.0     0.0   1.12711
FORCE          3      23       0   1.0     0.0     0.0  -.002513
FORCE          3      24       0   1.0     0.0     0.0   .284575
FORCE          3      25       0   1.0     0.0     0.0  -7.678-4
FORCE          3      26       0   1.0     0.0     0.0  -.001536
FORCE          3      27       0   1.0     0.0     0.0   .182808
FORCE          3      28       0   1.0     0.0     0.0  -.001536
FORCE          3      29       0   1.0     0.0     0.0   .337745
FORCE          3      30       0   1.0     0.0     0.0  -.001536
FORCE          3      31       0   1.0     0.0     0.0   .274724
FORCE          3      32       0   1.0     0.0     0.0  -7.678-4
FORCE          3      33       0   1.0     0.0     0.0  -6.980-5
FORCE          3      34       0   1.0     0.0     0.0   .424717
FORCE          3      35       0   1.0     0.0     0.0  -1.396-4
FORCE          3      36       0   1.0     0.0     0.0  -.026877
FORCE          3      37       0   1.0     0.0     0.0  -1.396-4
FORCE          3      38       0   1.0     0.0     0.0  -.058107
FORCE          3      39       0   1.0     0.0     0.0  -1.396-4
FORCE          3      40       0   1.0     0.0     0.0  -.10246
$...............................................................................
```

FSW Airplane in Antisymmetric Maneuvers

The FSW airplane of Example HA144A is reconsidered here for its lateral-directional stability characteristics and loading (Figure 7-12). The half-span model is modified to add a sweptback fin and to consider antisymmetrical motions plus the effects of a 25% chord aileron and 25% chord rudder. The right-half fin is assumed to weigh 50 Ibs. and is idealized as shown in the side view in Figure 7-12(b) with a sweepback angle of 30 deg and no taper. Two weights are located at the one-quarter and three-quarter chord of the fin at its midspan location and are assumed to be connected to its 50% chord elastic axis by rigid streamwise bars. The weights per side are assumed to be 30 lbs forward and 20 Ibs aft, yielding a fin centroid at 45% of its chord. Since the fin is assumed to have the same stiffness properties as the wing, then the right-side fin has half of the wing section properties. The aileron is shown on the wing in the plan view of Figure 7-12(a).

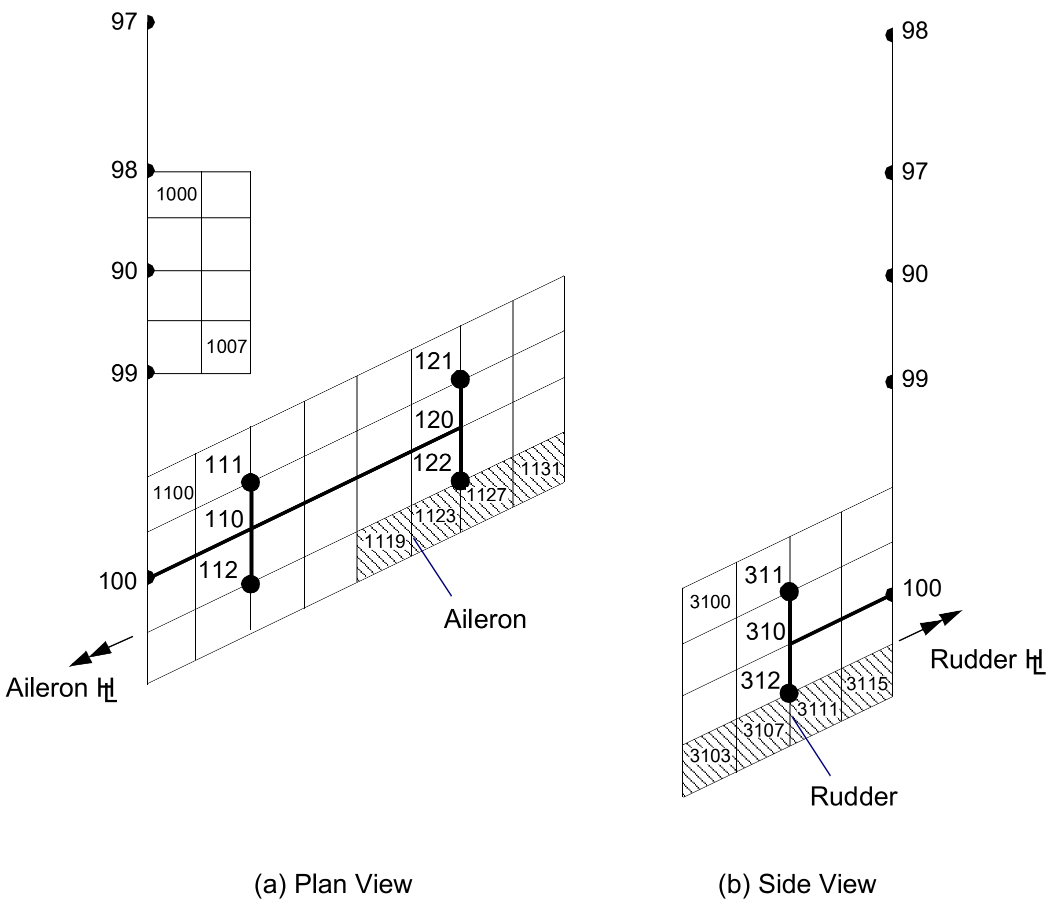

Figure 7-12 Idealization of Half-Span FSW Configuration Lateral-Directional Model

The Bulk Data Section is only slightly different from that of Example HA144A with the addition of the fin aileron, and rudder as the new control surfaces. The SPC1 constraints are modified to permit the antisymmetric degrees of freedom. GRIDs 310, 311, and 312 are added for the fin, CBAR 310 provides the fin elastic axis, and RBARs 311 and 312 connect the fin masses CONM2 311 and 312 to the elastic axis. The aerodynamic reference geometry and coordinates are given on the AEROS entry.

This entry lists:

- CORD2R

  This is the NACA coordinate system and is used as a reference for the stability derivatives.
- the reference chord of 10.0 ft
- the reference span of 40.0 ft
- the reference area of the half-model of 200.0 sq. ft
- SYMXZ = -1 for antisymmetric motion

The aerodynamic model also requires the addition of the fin using CAERO1 3100 and its spline SPLINE2 3100 with its axis on CORD2R 300 and connected to the SET1 3100 grid points.

The control surfaces are defined by AESURF and AELIST entries along with the coordinate systems whose y-axes define their hinge lines. AESURF 517 is the aileron and includes the trailing edge boxes on the outboard half of the wing as enumerated on AELIST 2000. The aileron rotation is assumed to be positive trailing-edge up on the right wing as given by CORD2R 110; this definition of positive aileron gives a positive rolling moment (right wing down). AESURF 518 is the rudder and includes the four trailing edge boxes on the fin as listed on AELIST 3000. A trailing-edge left rudder rotation gives a positive side force from the rudder so the rudder hinge line is defined by CORD2R 301.

For use in a later example, the above data are separated into the input file HA144D_MODEL.DAT as shown in Listing 7-14, and included in the present example using the INCLUDE entry.

The AESTAT entry defines the motions that respond to the control surface inputs. In the lateral-directional case these are: sideslip, $\beta = \text{SIDES}$; roll rate, $pb/2V = \text{ROLL}$; yaw rate, $rb/2V = \text{YAW}$; the lateral (side) acceleration, $\ddot{y}/g = \text{URDD2}$; and the rotational accelerations in roll, $\dot{p}/g = \text{URDD4}$, and yaw, $\dot{r}/g = \text{URDD6}$. These six motions are defined on AESTAT entries 511 through 516. PARAM,AUNITS permits load factor units for the accelerations.

Two subsonic trim conditions are considered. The first, TRIM 1, uses the sea-level value of dynamic pressure $\bar{q} = 1200 \text{ psf}$ at a Mach number of $m = 0.9$ and finds the steady roll solution for an aileron rotation of $\delta_a = \text{AILERON} = 25 \text{ deg} = 0.436332 \text{ rad}$, no yaw rate, $rb/2V = \text{YAW} = 0.0$, no lateral (side) acceleration, $\ddot{y}/g = \text{URDD2} = 0.0$, and no rotational accelerations, $\dot{p}/g = \text{URDD4} = 0.0$ and $\dot{r}/g = \text{URDD6} = 0.0$. The second trim condition, TRIM 2, is an abrupt roll at high speed, and assumes zero roll and yaw rates, $pb/2V = \text{ROLL}$ and $rb/2V = \text{YAW} = 0.0$, and no side or yaw accelerations, $\text{URDD2} = \text{URDD6} = 0.0$. The ENDDATA entry completes the Bulk Data Section.

The Case Control Section begins with three title commands. Using ECHO = BOTH prints the input data with and without the annotations. SPC = 1 enforces the constraints in the Bulk Data Section. Using DISP = STRESS = FORCE = AEROF = APRES = ALL calculates and prints all of these derived quantities from the analysis. The two subcases request that the two input trim cases be analyzed. The OUTPUT(PLOT) and remaining entries request plots of the deformed structure overlaid on the undeformed structure. The Case Control Section ends with BEGIN BULK.

The Executive Control Section begins with the identification ID MSC, HA144D. TIME 5 limits the total computing time to 5.0 CPU minutes. SOL 144 calls for the Static Aeroelastic Response DMAP sequence. The Executive Control Section is concluded with the CEND entry.

The input data file is shown in Listing 7-15; the sorted Bulk Data are in Listing 7-16, and those are followed by selected output in Listing 7-17. Highlights of the selected output are discussed next.

The OUTPUT FROM THE GRID POINT WEIGHT GENERATOR shows the effect of the additional fin weight. The half-airplane now weighs 8,050 lbs, and the centroid is now 2.276 ft aft of GRID 90 and 2.484 ft outboard from the centerline.

The restrained lateral-directional stability derivatives are defined by:

Side Force

$$C_Y = C_{Y_\beta}\beta + C_{Y_{\delta_a}}\delta_a + C_{Y_{\delta_r}}\delta_r + C_{Y_p}\frac{pb}{2V} + C_{Y_r}\frac{rb}{2V} + C_{Y_{\ddot{y}}}\frac{\ddot{y}}{g} + C_{Y_{\dot{p}}}\frac{\dot{p}b}{2g} + C_{Y_{\dot{r}}}\frac{\dot{r}b}{2g} \tag{7-5}$$

Rolling Moment

$$C_l = C_{l_\beta}\beta + C_{l_{\delta_a}}\delta_a + C_{l_{\delta_r}}\delta_r + C_{l_p}\frac{pb}{2V} + C_{l_r}\frac{rb}{2V} + C_{l_{\ddot{y}}}\frac{\ddot{y}}{g} + C_{l_{\dot{p}}}\frac{\dot{p}b}{2g} + C_{l_{\dot{r}}}\frac{\dot{r}b}{2g} \tag{7-6}$$

Yawing Moment

$$C_n = C_{n_\beta}\beta + C_{n_{\delta_a}}\delta_a + C_{n_{\delta_r}}\delta_r + C_{n_p}\frac{pb}{2V} + C_{n_r}\frac{rb}{2V} + C_{n_{\ddot{y}}}\frac{\ddot{y}}{g} + C_{n_{\dot{p}}}\frac{\dot{p}b}{2g} + C_{n_{\dot{r}}}\frac{\dot{r}b}{2g} \tag{7-7}$$

The rotations of the mean axes in the lateral-directional case are defined in a similar manner to those in the longitudinal case defined by Rodden and Love (1985) [Reference 51]. However, in the lateral-directional case there are two sets of rotations that are required in the equations of motion when using restrained aeroelastic derivatives: one is the rotation of the mean x-axis in the xy-plane, and the other is the rotation of the mean y-axis in the yz-plane.

The rotation of the mean x-axis in the xy-plane is

$$\beta_m = \beta_{m_\beta}\beta + \beta_{m_{\delta_a}}\delta_a + \beta_{m_{\delta_r}}\delta_r + \beta_{m_p}\frac{pb}{2V} + \beta_{m_r}\frac{rb}{2V} + \beta_{m_{\ddot{y}}}\frac{\ddot{y}}{g} + \beta_{m_{\dot{p}}}\frac{\dot{p}b}{2g} + \beta_{m_{\dot{r}}}\frac{\dot{r}b}{2g} \tag{7-8}$$

The rotation of the mean y-axis in the yz-plane is

$$\gamma_m = \gamma_{m_\beta}\beta + \gamma_{m_{\delta_a}}\delta_a + \gamma_{m_{\delta_r}}\delta_r + \gamma_{m_p}\frac{pb}{2V} + \gamma_{m_r}\frac{rb}{2V} + \gamma_{m_{\ddot{y}}}\frac{\ddot{y}}{g} + \gamma_{m_{\dot{p}}}\frac{\dot{p}b}{2g} + \gamma_{m_{\dot{r}}}\frac{\dot{r}b}{2g} \tag{7-9}$$

The derivatives are printed in the table NONDIMENSIONAL STABILITY AND CONTROL DERIVATIVE COEFFICIENTS and the mean axis rotations are printed in the second (for the angle β_m) and third (for the angle γ_m) rows of INTERMEDIATE MATRIX... HP and are listed in Table 7-6 for the two restraint conditions. Note that the angular acceleration derivatives and rotations are divided by $b/2$, because of their definitions in (7-5) through (7-9), just as the pitch acceleration terms are divided by $\bar{c}/2$ in Example HA144A (p. 200). Note also that the values of β_{m_β} and γ_{m_β} are obtained by adding 1.0 to the tabulated rotations.

The trim solutions follow the printouts of the stability derivatives. The steady roll trim solution for $\delta_a = 25 \text{ deg} = 0.436332 \text{ rad}$ is

$$\frac{pb}{2V} = 0.2600$$
$$\beta = -0.01824 \text{ rad} = -1.05°$$
$$\delta_r = 0.02059 \text{ rad} = 1.18°$$

The trim requirement for positive rudder is consistent with the lifting surface theory predicting proverse aileron yaw. To predict adverse yaw from the aileron requires the additional ability to predict induced drag on the lifting surfaces. It should also be noted that the predicted dihedral effect C_{l_β} does not include the effects from the sweep of the planform.

The second trim solution is the abrupt roll at high speed. The solution is

$$\dot{p}/g = 4.454 \text{ rad/ft or } \dot{p} = 8211 \text{ deg/s}^2$$
$$\beta = -0.06297 \text{ rad} = -3.61°$$
$$\delta_r = 0.01100 \text{ rad} = 0.63°$$

The pressure data and aerodynamic box forces and moments are shown for the high-speed maneuvers. These forces, moments, and data are followed by deflections relative to the support point at GRID 90. Finally, the forces and stresses in the CBAR elements are presented.

Table 7-6 Lateral-Directional Derivatives of FSW Airplane

Derivative	Rigid Value	Restrained Value at $\bar{q}$ = 1200 psf	Unrestrained Value at $\bar{q}$ = 1200 psf
C_{Y_β}	-0.7158	-0.6697	-0.7260
C_{l_β}	-0.3276	-0.02825	-0.02707
C_{n_β}	0.2592	0.2425	0.2630
$C_{Y_{\delta_a}}$	-0.1082	-0.1142	-0.1026
$C_{l_{\delta_a}}$	0.2748	0.2993	0.2625
$C_{n_{\delta_a}}$	0.03948	0.04149	0.03753
$C_{Y_{\delta_a}}$	0.3491	0.2997	0.3381
$C_{l_{\delta_r}}$	0.03745	0.03508	0.03229

Table 7-6 Lateral-Directional Derivatives of FSW Airplane (Continued)

Derivative	Rigid Value	Restrained Value at $\bar{q}$ = 1200 psf	Unrestrained Value at $\bar{q}$ = 1200 psf
$C_{n_{\delta_r}}$	-0.1707	-0.1526	-0.1665
C_{Y_p}	0.07965	0.1210	0.09466
C_{l_p}	-0.4185	-0.5070	-0.4448
C_{n_p}	-0.02605	-0.04054	-0.03138
C_{Y_r}	0.7233	0.6676	0.7285
C_{l_r}	0.04299	0.03858	0.03630
C_{n_r}	-0.2775	-0.2573	-0.2794
$C_{Y_{\dot{y}}}$	-	0.0007188	-
$C_{l_{\dot{y}}}$	-	0.00003018	-
$C_{n_{\dot{y}}}$	-	-0.0002602	-
$C_{Y_{\dot{p}}}$	-	0.0001011	-
$C_{l_{\dot{p}}}$	-	-0.0001818	-
$C_{n_{\dot{p}}}$	-	-0.00003559	-
$C_{Y_{\dot{r}}}$	-	-0.001107	-
$C_{l_{\dot{r}}}$	-	-0.00004991	-
$C_{n_{\dot{r}}}$	-	0.0004040	-
β_{m_β}	1.0	1.006878	-
$\beta_{m_{\delta_a}}$	-	-0.2378	-
$\beta_{m_{\delta_r}}$	-	-0.01859	-
β_{m_p}	-	0.4273	-
β_{m_r}	-	-0.01403	-
$\beta_{m_{\dot{y}}}$	-	0.00001049	-
$\beta_{m_{\dot{p}}}$	-	0.001214	-
$\beta_{m_{\dot{r}}}$	-	-0.000001260	-
γ_{m_β}	-	-0.9630	-
$\gamma_{m_{\delta_a}}$	-	-0.006602	-
$\gamma_{m_{\delta_r}}$	-	0.02767	-
γ_{m_p}	-	0.006442	-

Table 7-6 Lateral-Directional Derivatives of FSW Airplane (Continued)

Derivative	Rigid Value	Restrained Value at $\bar{q}$ = 1200 psf	Unrestrained Value at $\bar{q}$ = 1200 psf
γ_{m_r}	-	0.04077	-
$\gamma_{m_{\ddot{y}}}$	-	-0.0003089	-
$\gamma_{m_{\dot{p}}}$	-	0.00000291	-
$\gamma_{m_{\dot{r}}}$	-	0.0008229	-

Listing 7-14 HA144D_MODEL.DAT Input File

```
$*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
$                                                                        $
$        THE ANNOTATIONS IN THIS INPUT DECK ARE INTENDED TO              $
$        EXPLAIN THE DATA ON THE CARD IMAGES FOR THIS SPECIFIC           $
$        EXAMPLE WITHOUT REFERENCE TO THE VARIOUS MANUALS WHERE          $
$        MORE GENERAL DESCRIPTIONS WILL BE FOUND.                        $
$                                                                        $
$*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
$                                                                        $
$                       * * * STRUCTURAL DATA * * *                      $
$                                                                        $
$                            (LB-FT-SEC SYSTEM)                          $
$                                                                        $
$                          * * GRID GEOMETRY * *                         $
$                                                                        $
$        GRID  90 - 100 (T3) FUSELAGE POINTS                             $
$        GRID 110 - 122 (T3) WING POINTS                                 $
$        GRID 310 - 312 (t3) FIN POINTS                                  $
$                                                                        $
$                            * FUSELAGE GRID *                           $
$                                                                        $
$        THE GRID ENTRY DEFINES THE LOCATION OF A STRUCTURAL GRID        $
$        POINT.  LISTED ARE ITS COORDINATE SYSTEM ID, ITS LOCATION,      $
$        THE ID OF THE COORDINATE SYSTEM IN WHICH ITS DISPLACEMENTS      $
$        ARE DEFINED, ITS PERMANENT SINGLE-POINT CONSTRAINTS AND         $
$        ITS ASSOCIATED SUPERELEMENT ID.                                 $
$                                                                        $
$       ID      CP      X1      X2      X3      CD      PS      SEID
GRID    90              15.     0.      0.
GRID    97              0.      0.      0.
GRID    98              10.     0.      0.
GRID    99              20.     0.      0.
GRID    100             30.     0.      0.
$                                                                        $
$                            * WING GRID *                               $
$                                                                        $
$       ID      CP      X1      X2      X3      CD      PS      SEID
GRID    111             24.61325 +5.    0.
GRID    110             27.11325 +5.    0.
GRID    112             29.61325 +5.    0.
GRID    121             18.83975+15.    0.
GRID    120             21.33975+15.    0.
GRID    122             23.83975+15.    0.
$                                                                        $
$                            * FIN GRID *                                $
$                                                                        $
GRID    310             32.88675+0.     5.
GRID    311             30.38675+0.     5.
GRID    312             35.38675+0.     5.
$                                                                        $
$                 * * STRUCTURAL STIFFNESS PROPERTIES * *                $
$                                                                        $
$                         * FUSELAGE STRUCTURE *                         $
$                                                                        $
$        THE CBAR ENTRY DEFINES A SIMPLE BEAM ELEMENT.  LISTED ARE       $
$        ITS PROPERTY ENTRY ID, THE TWO GRID POINTS JOINED BY THE        $
$        BEAM AND COMPONENTS OF A VECTOR FROM THE FIRST POINT.           $
$        THIS VECTOR DEFINES THE DIRECTION OF THE STRUCTURAL DE-         $
$        FLECTION OF THE POINT AND ITS POSITIVE SENSE.                   $
$                                                                        $
$       EID     PID     GA      GB      X1,GO   X2      X3
CBAR    101     100     97      98      0.      0.      1.
CBAR    102     100     98      90      0.      0.      1.
CBAR    100     100     90      99      0.      0.      1.
CBAR    103     100     99      100     0.      0.      1.
$                                                                        $
$        THE PBAR ENTRY DEFINES GEOMETRIC PROPERTIES OF THE BEAM.        $
$        LISTED ARE ITS ASSOCIATED MATERIAL ENTRY ID, ITS CROSS SEC-     $
$        TIONAL AREA, AREA MOMENTS OF INERTIA, TORSIONAL MOMENT          $
$        OF INERTIA AND NON-STRUCTURAL MASS PER UNIT AREA.  THE          $
$        OPTIONAL CONTINUATION ENTRY CONTAINS STRESS RECOVERY            $
$        COEFFICIENTS, that is, Y,Z COORDINATES WHERE STRESSES ARE          $
$        TO BE COMPUTED.  K1 AND K2 ARE AREA FACTORS FOR SHEAR           $
$        STIFFNESS (DEFAULT IS BLANK; THEN SHEAR STIFFNESS IS            $
$        INFINITE, that is, SHEAR FLEXIBILITY IS ZERO.  I12 IS THE          $
$        AREA PRODUCT OF INERTIA.                                        $
$                                                                        $
$       PID     MID     A       I1      I2      J       NSM
PBAR    100     1       2.0     .173611 0.15    0.5                     +PB1F
$       C1      C2      D1      D2      E1      E2      F1      F2
+PB1F   1.0     1.0     1.0     -1.0    -1.0    1.0     -1.0    -1.0    +PB2F
$       K1      K2      I12
+PB2F                   0.0
```

Listing 7-14 HA144D_MODEL.DAT Input File (Continued)

```
$                           * WING STRUCTURE *                          $
$                                                                       $
$       EID     PID     GA      GB      X1,GO   X2      X3
CBAR    110     101     100     110     0.      0.      1.
CBAR    120     101     110     120     0.      0.      1.
$                                                                       $
$        THE RBAR ENTRY DEFINES A RIGID BAR.  LISTED ARE THE GRID       $
$        POINTS AT EACH END AND THE DEPENDENT AND INDEPENDENT DOFS      $
$        AT EACH END.  THE NUMBER OF INDEPENDENT DOFS AT THE TWO        $
$        ENDS MUST EQUAL SIX.  BY DEFAULT THOSE NOT DECLARED INDE-      $
$        PENDENT ARE MADE DEPENDENT.                                    $
$                                                                       $
$       EID     GA      GB      CNA     CNB     CMA     CMB
RBAR    111     110     111     123456
RBAR    112     110     112     123456
RBAR    121     120     121     123456
RBAR    122     120     122     123456
$                                                                       $
PBAR    101     1       1.5     0.173611+2.0    0.462963                +PB1W
+PB1W   0.5     3.0     0.5     -3.0    -0.5    3.0     -0.5    -3.0    +PB2W
+PB2W                   0.0
$                                                                       $
$                           * FIN STRUCTURE *                           $
$                                                                       $
CBAR    310     301     100     310     0.      0.      1.
$                                                                       $
RBAR    311     310     311     123456
RBAR    312     310     312     123456
$                                                                       $
PBAR    301     1       .75     .086806 1.0     .231482                 +PB1FI
+PB1FI  0.5     3.0     0.5     -3.0    -0.5    3.0     -0.5    -3.0    +PB2FI
+PB2FI                  0.
$
$        THE MAT1 ENTRY DEFINES THE MATERIAL PROPERTIES.  LISTED        $
$        ARE ITS ID, ITS ELASTIC MODULUS, SHEAR MODULUS, POISSONS       $
$        RATIO, MASS DENSITY, TEMPERATURE EXPANSION COEFFICIENT,        $
$        REFERENCE TEMPERATURE AND A STRUCTURAL DAMPING COEFFICIENT.    $
$                                                                       $
$       MID     E       G       NU      RHO     A       TREF    GE
MAT1    1       1.44+9  5.40+8
$                                                                       $
$                 * * MASS AND INERTIA PROPERTIES * *                   $
$                                                                       $
$                          * FUSELAGE MASSES *                          $
$                                                                       $
$        THE CONM2 ENTRY DEFINES A CONCENTRATED MASS.  LISTED ARE       $
$        ITS ID, GRID LOCATION, COORDINATE SYSTEM TO LOCATE THE         $
$        CENTER OF GRAVITY, THE MASS VALUE AND THE LOCATION OF          $
$        THE CENTER OF GRAVITY RELATIVE TO THE GRID LOCATION.           $
$                                                                       $
$       EID     G       CID     M       X1      X2      X3
CONM2   97      97      0       1500.0
CONM2   98      98      0       1500.0
CONM2   99      99      0       1500.0
CONM2   100     100     0       1500.0
$                                                                       $
$                            * WING MASSES *                            $
$                                                                       $
CONM2   111     111     0       600.0
CONM2   112     112     0       400.0
CONM2   121     121     0       600.0
CONM2   122     122     0       400.0
$                                                                       $
$                            * FIN MASSES *                             $
$                                                                       $
CONM2   311     311     0       30.0
CONM2   312     312     0       20.0
$                                                                       $
$                    * * STRUCTURAL PARAMETERS * *                      $
$                                                                       $
$        THE PARAM,GRDPNT,XX ENTRY CAUSES THE GRID POINT WEIGHT         $
$        GENERATOR TO BE EXECUTED USING GRID POINT XX AS THE REF-       $
$        ERENCE POINT.  THEN THE INERTIA MATRIX, THE TRANSFER MATRIX    $
$        FROM BASIC TO PRINCIPAL AXES AND OTHER PERTINENT INERTIA       $
$        DATA ARE PRINTED.                                              $
$                                                                       $
PARAM   GRDPNT  90
$                                                                       $
$        THE PARAM,WTMASS,GINV CAUSES ALL THE STRUCTURAL MASSES AND     $
$        MASS DENSITIES TO BE MULTIPLIED BY GINV (that is, BY ONE OVER     $
$        THE ACCELERATION OF GRAVITY).  THE DYNAMIC PRESSURE SUPPLIED   $
$        FOR AERODYNAMIC FORCE CALCULATIONS WILL NOT BE MULTIPLIED      $
$        BY GINV.                                                       $
```

Listing 7-14 HA144D_MODEL.DAT Input File (Continued)

```
$                                                                       $
PARAM   WTMASS  .031081
$                                                                       $
$                     * * STRUCTURAL CONSTRAINTS * *                    $
$                                                                       $
$        THE SPC1 ENTRY CONSTRAINS THE LISTED GRID POINTS IN THE        $
$        SPECIFIED DOF COMPONENTS.                                      $
$                                                                       $
$       SID     C       G1      G2      G3      G4
SPC1    1       135     90
SPC1    1       35      97      98      99      100
$                                                                       $
$        THE SUPORT ENTRY IDENTIFIES A GRID POINT OR A SCALAR POINT     $
$        AND SPECIFIES THE DOF COMPONENTS IN WHICH THE USER DESIRES     $
$        REACTIONS TO BE APPLIED TO PREVENT RIGID BODY MOTION.  IT      $
$        THUS INVOKES THE SOLUTION OF THE BALANCE EQUATIONS TO DETER-   $
$        MINE THE REACTIONS.  IN THE STATIC AEROELASTIC SOLUTION        $
$        THE DOF COMPONENTS MUST BE CONSISTENT WITH THE UNDEFINED       $
$        VARIABLES ON THE TRIM ENTRIES.                                 $
$                                                                       $
$        ID      C
SUPORT  90      246
$                                                                       $
$        THE OMIT1 ENTRY IDENTIFIES GRID POINTS TO BE OMITTED FROM      $
$        THE REMAINDER OF THE ANALYSIS.                                 $
$                                                                       $
$        ID      G       G
OMIT1   4       110     120     310
$                                                                       $
$        THIS CORD2R ENTRY DEFINES THE AERO COORDINATE SYSTEM           $
$        FLAGGED BY THE AEROS ENTRY.  THE ORIGIN IS AT THE CANARD       $
$        QUARTER CHORD.  LISTED ARE THE ORIGIN, A POINT ALONG THE       $
$        Z AXIS AND A POINT IN THE X-Z PLANE, ALL IN THE RID            $
$        COORDINATE SYSTEM.                                             $
$                                                                       $
$       CID     RID     A1      A2      A3      B1      B2      B3
CORD2R  1       0       12.5    0.      0.      12.5    0.      10.     +CRD1
$       C1      C2      C3
+CRD1   20.     0.      0.
$                                                                       $
$        THIS CORD2R ENTRY DEFINES THE NACA COORDINATE SYSTEM TO        $
$        WHICH ALL THE STABILITY DERIVATIVES AND TRIM CONDITIONS        $
$        WILL BE REFERENCED.                                            $
$                                                                       $
$       CID     RID     A1      A2      A3      B1      B2      B3
CORD2R  100     0       15.0    0.0     0.0     15.0    0.0     -10.0   +CRD100
$       C1      C2      C3
+CRD100 0.0     0.0     0.0
$                                                                       $
$                                                                       $
$                       * WING AERODYNAMIC MODEL *                      $
$                                                                       $
$        THE CAERO1 ENTRY IS USED FOR DOUBLET-LATTICE AERODYNAMICS.     $
$        LISTED ARE ITS PAERO ENTRY ID AND THE COORDINATE SYSTEM        $
$        FOR LOCATING THE INBOARD AND OUTBOARD LEADING EDGE POINTS      $
$        (1 AND 4).  NSPAN AND NCHORD, OR LSPAN AND LCHORD, ARE         $
$        USED TO PARTITION THE WING INTO AERODYNAMIC PANELS,            $
$        THE FORMER FOR UNIFORMLY SPACED PANELS AND THE LATTER          $
$        FOR NON-UNIFORMLY SPACED PANELS.  IGID IS THE ID OF ITS        $
$        ASSOCIATED INTERFERENCE GROUP.  THE CONTINUATION ENTRY         $
$        DEFINES POINTS 1 AND 4, THE ROOT CHORD AND TIP CHORD.          $
$        THE BOXES FORMED BY THE GRID LINES WILL BE NUMBERED            $
$        BEGINNING WITH EID SO CHOOSE A NUMBER THAT IS UNIQUE,          $
$        AND IS GREATER THAN ALL STRUCTURAL GRID, SCALAR AND            $
$        EXTRA POINT IDS.                                               $
$                                                                       $
$       EID     PID     CP      NSPAN   NCHORD  LSPAN   LCHORD  IGID
CAERO1  1100    1000            8       4                       1       +CAW
$      ( FWD LEFT POINT  )     CHORD  ( FWD RIGHT POINT   )     CHORD
$       X1      Y1      Z1      X12     X4         Y4   Z4      X14
+CAW    25.     0.      0.      10.     13.45299+20.    0.      10.
$                                                                       $
$        THE PAERO1 ENTRY IS REQUIRED EVEN THOUGH IT IS NON-FUNCTIONAL  $
$        (BECAUSE THERE ARE NO ASSOCIATED BODIES IN THIS EXAMPLE).      $
$                                                                       $
$       PID     B1      B2      B3      B4      B5      B6
PAERO1  1000
$                                                                       $
$                      * CANARD AERODYNAMIC MODEL *                     $
$                                                                       $
CAERO1  1000    1000            2       4                       1       +CAC
+CAC    10.     0.      0.      10.     10.     5.      0.      10.
$                                                                       $
$                       * FIN AERODYNAMIC MODEL *                       $
$                                                                       $
CAERO1  3100    1000            4       4                       1       +CA1FI
+CA1FI  30.7735 0.      10.     10.     25.     0.      0.      10.
```

Listing 7-14 HA144D_MODEL.DAT Input File (Continued)

```
$                                                                       $
$               * * SPLINE FIT ON THE LIFTING SURFACES * *              $
$                                                                       $
$                    * BEAM SPLINE FIT ON THE WING *                    $
$                                                                       $
$        THE SPLINE2 ENTRY SPECIFIES A BEAM SPLINE FOR INTERPOLAT-      $
$        ION OVER THE REGION OF THE CAERO ENTRY (ID1 AND ID2 ARE        $
$        THE FIRST AND LAST BOXES IN THIS REGION).  SETG REFERS         $
$        TO A SET1 ENTRY WHERE THE STRUCTURAL GRID POINTS ARE           $
$        DEFINED.  DZ AND DTOR ARE SMOOTHING CONSTANTS FOR LINEAR       $
$        ATTACHMENT AND TORSIONAL FLEXIBILITIES.  CID IDENTIFIES        $
$        THE CORD2R ENTRY THAT DEFINES THE SPLINE AXIS.  DTHX AND       $
$        DTHY ARE ROTATIONAL ATTACHMENT FLEXIBILITIES (-1. SPECIFIES    $
$        NO ATTACHMENT).                                                $
$                                                                       $
$       EID     CAERO   ID1     ID2     SETG    DZ      DTOR    CID
SPLINE2 1601    1100    1100    1131    1100    0.      1.      2       +SPW
$       DTHX    DTHY
+SPW    -1.     -1.
$                                                                       $
$        THE SET1 ENTRY DEFINES THE SETS OF STRUCTURAL GRID POINTS      $
$        TO BE USED BY THE BEAM SPLINE FOR INTERPOLATION.               $
$                                                                       $
$       SID     G1      G2      G3      G4
SET1    1100    99      100     111     112     121     122
$                                                                       $
$                  * BEAM SPLINE FIT ON THE CANARD *                    $
$                                                                       $
SPLINE2 1501    1000    1000    1007    1000    0.      1.      1       +SPC
+SPC    1.      -1.
$                                                                       $
SET1    1000    98      99
$                                                                       $
$                    * BEAM SPLINE FIT ON THE FIN *                     $
$                                                                       $
SPLINE2 3100    3100    3100    3115    3100    0.      1.      300     +SP2FI
+SP2FI  -1.     -1.
$                                                                       $
SET1    3100    99      100     311     312
$                                                                       $
$        THE CORD2R ENTRY DEFINES THE COORDINATE SYSTEM IN WHICH THE    $
$        BEAM SPLINE EXTENDS ALONG THE WING Y-AXIS.  IT LISTS THE       $
$        ORIGIN, A POINT ALONG THE Z-AXIS AND A POINT IN THE X-Z        $
$        PLANE.                                                         $
$                                                                       $
$                         * WING SPLINE AXIS *                          $
$                                                                       $
$       CID     CS      A1      A2      A3      B1      B2      B3
CORD2R  2       0       30.     0.      0.      30.     0.      10.     +CRD2
$       C1      C2      C3
+CRD2   38.66025+5.0    0.
$                                                                       $
$                          * FIN SPLINE AXIS *                          $
$                                                                       $
CORD2R  300     0       30.0    0.      0.      30.0    10.0    0.      +CRD2FI
+CRD2FI 20.0    0.      5.7735
$                                                                       $
$                  * CONTROL SURFACE DEFINITION *                       $
$                                                                       $
$        THE AESURF ENTRY DEFINES AN AERODYNAMIC CONTROL SURFACE.       $
$        LISTED ARE THE ALPHANUMERIC NAME OF THE SURFACE, THE ID        $
$        OF A COORDINATE SYSTEM THAT DEFINES THE HINGE LINE AND         $
$        THE ID OF AN AELIST ENTRY.                                     $
$                                                                       $
$       ID      LABEL   CID1    ALID1   CID2    ALID2
AESURF  517     AILERON 110     2000
AESURF  518     RUDDER  301     3000
$                                                                       $
$        THE AELIST ENTRY LISTS AERODYNAMIC BOXES THAT LIE ON THE       $
$        CONTROL SURFACE.                                               $
$                                                                       $
$       SID     E1      E2      E3      ETC
AELIST  2000    1119    1123    1127    1131
AELIST  3000    3103    3107    3111    3115
$                                                                       $
$                    * CONTROL SURFACE HINGE LINES *                    $
$                                                                       $
$                            * AILERON *                                $
CORD2R  110     0       26.7265 10.0    0.      26.7265 10.0    -10.0   +CRD2A
+CRD2A  36.7265 15.7735 0.
$                                                                       $
$                             * RUDDER *                                $
CORD2R  301     0       32.5    0.      0.      32.5    -10.    0.0     +CRD2R
+CRD2R  22.5    0.      5.7735
$                                                                       $
```

Listing 7-15 Input Files for FSW Airplane in Antisymmetric Maneuvers

```
   N A S T R A N    E X E C U T I V E    C O N T R O L    D E C K    E C H O


ID MSC, HA144D
$$$$$$$$  HANDBOOK FOR AEROELASTIC ANALYSIS EXAMPLE HA144D      $$$$$$$$
$                                                                      $
$       MODEL DESCRIPTION        30 DEG FORWARD SWEPT WING WITH        $
$                                AILERON, CANARD AND AFT SWEPT         $
$                                VERTICAL FIN AND RUDDER.              $
$                                BAR MODEL WITH DUMBBELL MASSES.       $
$                                                                      $
$       SOLUTION                 ANTISYMMETRIC STATIC STABILITY        $
$                                DERIVATIVE ANALYSIS USING DOUBLET-    $
$                                LATTICE AERODYNAMICS AT MACH 0.9.     $
$                                                                      $
$       OUTPUT                   PLOTS OF THE STICK MODEL AND AERO     $
$                                GRID, LISTS OF RESTRAINED AND         $
$                                UNRESTRAINED SYMMETRIC STATIC         $
$                                STABILITY DERIVATIVES, THE            $
$                                AERODYNAMIC FORCES AND PRESSURES,     $
$                                AND STRESSES AND DEFLECTIONS FOR      $
$                                ROLL MANEUVERS.                       $
$                                                                      $
$$$$$$$$                                                        $$$$$$$$
TIME 5 $ CPU TIME IN MINUTES
SOL 144 $ STATIC AERO
CEND
```

Listing 7-15 Input Files for FSW Airplane in Antisymmetric Maneuvers (Continued)

```
EXAMPLE HA144D: 30 DEG FWD SWEPT WING WITH CANARD & FIN                                      PAGE     2
ANTISYMMETRIC FLIGHT CONDITIONS, DOUBLET-LATTICE AERO
HALF-SPAN MODEL, STATIC ANTISYMMETRIC LOADING

                                    C A S E    C O N T R O L   D E C K   E C H O
            CARD
            COUNT
             1      TITLE = EXAMPLE HA144D: 30 DEG FWD SWEPT WING WITH CANARD & FIN
             2      SUBTI = ANTISYMMETRIC FLIGHT CONDITIONS, DOUBLET-LATTICE AERO
             3      LABEL = HALF-SPAN MODEL, STATIC ANTISYMMETRIC LOADING
             4        ECHO    = BOTH
             5        SPC     = 1   $ SYMMETRIC CONSTRAINTS
             6        DISP    = ALL $ PRINT ALL DISPLACEMENTS
             7        STRESS  = ALL $ PRINT ALL STRESSES
             8        FORCE   = ALL $ PRINT ALL FORCES
             9        AEROF   = ALL $ PRINT ALL AERODYNAMIC FORCES
            10        APRES   = ALL $ PRINT ALL AERODYNAMIC PRESSURES
            11      SUBCASE 1
            12        TRIM = 1      $ HIGH SUBSONIC SPEED STEADY ROLL
            13      SUBCASE 2
            14        TRIM = 2      $ HIGH SUBSONIC SPEED ABRUPT ROLL
            15      OUTPUT(PLOT)
            16        PLOTTER = NASTRAN
            17        SET 1 = ALL
            18        FIND SCALE, ORIGIN 1, SET 1
            19        PLOT SET 1
            20        PLOT STATIC DEFORMATION 0, ORIGIN 1, SET 1, OUTLINE
            21      BEGIN BULK
```

Listing 7-15 Input Files for FSW Airplane in Antisymmetric Maneuvers (Continued)

```
EXAMPLE HA144D: 30 DEG FWD SWEPT WING WITH CANARD & FIN                              PAGE     3
  ANTISYMMETRIC FLIGHT CONDITIONS, DOUBLET-LATTICE AERO

 HALF-SPAN MODEL, STATIC ANTISYMMETRIC LOADING

                         I N P U T   B U L K   D A T A   D E C K   E C H O

                        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                        $
                        INCLUDE HA144D_MODEL.DAT
                        $                                                                       $
                        $        THE PARAM,AUNITS,GINV PERMITS THE ACCELERATIONS ON THE TRIM    $
                        $        ENTRY TO BE SPECIFIED IN UNITS OF LOAD FACTOR, that is, IN G'S.   $
                        $                                                                       $
                        PARAM   AUNITS  .031081
                        $                       * * AERODYNAMIC DOFS * *                        $
                        $                                                                       $
                        $        THE AESTAT ENTRY LISTS TRIM VARIABLES USED TO SPECIFY          $
                        $        RIGID BODY MOTIONS.  THESE AND THE CONTROL SURFACE             $
                        $        ROTATIONS MAKE UP THE VARIABLES IN THE EQUATIONS OF            $
                        $        MOTION.                                                        $
                        $                                                                       $
                        $       ID      LABEL
                        AESTAT  511     SIDES
                        AESTAT  512     YAW
                        AESTAT  513     ROLL
                        AESTAT  514     URDD2
                        AESTAT  515     URDD4
                        AESTAT  516     URDD6
                        $                                                                       $
                        $                      * * * AERODYNAMIC DATA * * *                     $
                        $                                                                       $
                        $                           (LB-FT-SEC SYSTEM)                          $
                        $                                                                       $
                        $                        * * ELEMENT GEOMETRY * *                       $
                        $                                                                       $
                        $        THE AEROS ENTRY IS UNIQUE TO THE STATIC AEROELASTICITY         $
                        $        SOLUTION, SOL21.  ACSID IDENTIFIES THE AERO COORDINATE         $
                        $        SYSTEM, RCSID IDENTIFIES THE REFERENCE COORDINATE SYS-         $
                        $        TEM FOR RIGID BODY MOTION.  REFC IS THE REFERENCE CHORD.       $
                        $        REFB IS THE REFERENCE SPAN.  REFS IS THE REFERENCE WING        $
                        $        AREA.  SYMXZ AND SYMXY ARE SYMMETRY KEYS.                      $
                        $                                                                       $
                        $       ACSID   RCSID   REFC    REFB    REFS    SYMXZ   SYMXY
                        AEROS   1       100     10.0    40.0    200.0   -1
                        $                                                                       $
                        $                        * * TRIM CONDITIONS * *                        $
                        $                                                                       $
                        $        THE TRIM ENTRY SPECIFIES CONSTRAINTS FOR THE TRIM VARIABLES    $
                        $        LISTED ON THE AESTAT AND AESURF ENTRIES.  LISTED ARE ITS ID,   $
                        $        THE MACH NUMBER, DYNAMIC PRESSURE AND PAIRS OF TRIM VARI-      $
                        $        ABLES AND THEIR CONSTRAINED VALUES.  THOSE THAT ARE NOT        $
                        $        HELD FIXED MUST BE CONSTRAINED BY REACTION FORCES STIPU-       $
                        $        LATED ON THE SUPORT ENTRY.  SEE SECTION 3.5.3 OF THE THEO-     $
                        $        RETICAL MANUAL FOR MORE DETAILS.                               $
                        $                                                                       $
                        $        TRIM CONDITION 1: STEADY ROLL AT HIGH DYNAMIC PRESSURE         $
                        $                                                                       $
                        TRIM    1       0.9     1200.0  AILERON .436332 YAW     0.              +TR1
                        +TR1    URDD2   0.      URDD4   0.      URDD6   0.
                        $                                                                       $
                        $        TRIM CONDITION 2: ABRUPT ROLL AT HIGH DYNAMIC PRESSURE         $
                        $                                                                       $
                        TRIM    2       0.9     1200.0  AILERON .436332 YAW     0.              +TR2
                        +TR2    URDD2   0.      ROLL    0.      URDD6   0.
                        $                                 * * *                                 $
                        ENDDATA

                       INPUT BULK DATA CARD COUNT =     399
```

Listing 7-16 Sorted Bulk Data Entries for FSW Airplane in Antisymmetric Maneuvers

```
EXAMPLE HA144D: 30 DEG FWD SWEPT WING WITH CANARD & FIN                                                     PAGE    11
 ANTISYMMETRIC FLIGHT CONDITIONS, DOUBLET-LATTICE AERO

 HALF-SPAN MODEL, STATIC ANTISYMMETRIC LOADING

                                             S O R T E D   B U L K   D A T A   E C H O
           CARD
           COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
             1-        AELIST  2000    1119    1123    1127    1131
             2-        AELIST  3000    3103    3107    3111    3115
             3-        AEROS   1       100     10.0    40.0    200.0   -1
             4-        AESTAT  511     SIDES
             5-        AESTAT  512     YAW
             6-        AESTAT  513     ROLL
             7-        AESTAT  514     URDD2
             8-        AESTAT  515     URDD4
             9-        AESTAT  516     URDD6
            10-        AESURF  517     AILERON 110     2000
            11-        AESURF  518     RUDDER  301     3000
            12-        CAERO1  1000    1000            2       4                       1       +CAC
            13-        +CAC    10.     0.      0.      10.     10.     5.      0.      10.
            14-        CAERO1  1100    1000            8       4                       1       +CAW
            15-        +CAW    25.     0.      0.      10.     13.45299+20.    0.      10.
            16-        CAERO1  3100    1000            4       4                       1       +CA1FI
            17-        +CA1FI  30.7735 0.      10.     10.     25.     0.      0.      10.
            18-        CBAR    100     100     90      99      0.      0.      1.
            19-        CBAR    101     100     97      98      0.      0.      1.
            20-        CBAR    102     100     98      90      0.      0.      1.
            21-        CBAR    103     100     99      100     0.      0.      1.
            22-        CBAR    110     101     100     110     0.      0.      1.
            23-        CBAR    120     101     110     120     0.      0.      1.
            24-        CBAR    310     301     100     310     0.      0.      1.
            25-        CONM2   97      97      0       1500.0
            26-        CONM2   98      98      0       1500.0
            27-        CONM2   99      99      0       1500.0
            28-        CONM2   100     100     0       1500.0
            29-        CONM2   111     111     0       600.0
            30-        CONM2   112     112     0       400.0
            31-        CONM2   121     121     0       600.0
            32-        CONM2   122     122     0       400.0
            33-        CONM2   311     311     0       30.0
            34-        CONM2   312     312     0       20.0
            35-        CORD2R  1       0       12.5    0.      0.      12.5    0.      10.     +CRD1
            36-        +CRD1   20.     0.      0.
            37-        CORD2R  2       0       30.     0.      0.      30.     0.      10.     +CRD2
            38-        +CRD2   38.66025+5.0    0.
            39-        CORD2R  100     0       15.0    0.0     0.0     15.0    0.0     -10.0   +CRD100
            40-        +CRD100 0.0     0.0     0.0
            41-        CORD2R  110     0       26.7265 10.0    0.      26.7265 10.0    -10.0   +CRD2A
            42-        +CRD2A  36.7265 15.7735 0.
            43-        CORD2R  300     0       30.0    0.      0.      30.0    10.0    0.      +CRD2FI
            44-        +CRD2FI 20.0    0.      5.7735
            45-        CORD2R  301     0       32.5    0.      0.      32.5    -10.    0.0     +CRD2R
            46-        +CRD2R  22.5    0.      5.7735
            47-        GRID    90              15.     0.      0.
            48-        GRID    97              0.      0.      0.
            49-        GRID    98              10.     0.      0.
            50-        GRID    99              20.     0.      0.
            51-        GRID    100             30.     0.      0.
            52-        GRID    110             27.11325+5.     0.
            53-        GRID    111             24.61325+5.     0.
            54-        GRID    112             29.61325+5.     0.
            55-        GRID    120             21.33975+15.    0.
            56-        GRID    121             18.83975+15.    0.
            57-        GRID    122             23.83975+15.    0.
            58-        GRID    310             32.88675+0.     5.
            59-        GRID    311             30.38675+0.     5.
            60-        GRID    312             35.38675+0.     5.
            61-        MAT1    1       1.44+9  5.40+8
            62-        OMIT1   4       110     120     310
            63-        PAERO1  1000
            64-        PARAM   GRDPNT  90
            65-        PARAM   WTMASS  .031081
```

Listing 7-16 Sorted Bulk Data Entries for FSW Airplane in Antisymmetric Maneuvers (Continued)

```
PARAM   AUNITS  .31081
PBAR    100     1       2.0     .173611 0.15    0.5                     +PB1F
+PB1F   1.0     1.0     1.0     -1.0    -1.0    1.0     -1.0    -1.0    +PB2F
+PB2F                   0.0
PBAR    101     1       1.5     0.173611+2.0    0.462963                +PB1W
+PB1W   0.05    3.0     0.05    -3.0    -0.05   3.0     -0.05   -3.0    +PB2W
+PB2W                   0.0
PBAR    301     1       .75     .086806 1.0     .231482                 +PB1FI
+PB1FI  0.05    3.0     0.05    -3.0    -0.05   3.0     -0.05   -3.0    +PB2FI
+PB2FI                  0.
RBAR    111     110     111     123456
RBAR    112     110     112     123456
RBAR    121     120     121     123456
RBAR    122     120     122     123456
RBAR    311     310     311     123456
RBAR    312     310     312     123456
SET1    1000    98      99
SET1    1100    99      100     111     112     121     122
SET1    3100    99      100     311     312
SPC1    1       35      97      98      99      100
SPC1    1       135     90
SPLINE2 1501    1000    1000    1007    1000    0.      1.      1       +SPC
+SPC    1.      -1.
SPLINE2 1601    1100    1100    1131    1100    0.      1.      2       +SPW
+SPW    -1.     -1.
SPLINE2 3100    3100    3100    3115    3100    0.      1.      300     +SP2FI
+SP2FI  -1.     -1.
SUPORT  90      246
TRIM    1       0.9     1200.0  AILERON .436332 YAW     0.              +TR1
+TR1    URDD2   0.      URDD4   0.      URDD6   0.
TRIM    2       0.9     1200.0  AILERON .436332 YAW     0.              +TR2
+TR2    URDD2   0.      ROLL    0.      URDD6   0.
ENDDATA
TOTAL COUNT=        98
```

Listing 7-17 Output for FSW Airplane in Antisymmetric Maneuvers

```
 EXAMPLE HA144D: 30 DEG FWD SWEPT WING WITH CANARD & FIN                                                PAGE    15
   ANTISYMMETRIC FLIGHT CONDITIONS, DOUBLET-LATTICE AERO

   HALF-SPAN MODEL, STATIC ANTISYMMETRIC LOADING
                                 O U T P U T   F R O M   G R I D   P O I N T   W E I G H T   G E N E R A T O R
                                                         REFERENCE POINT =       90
                                                                   M O
                    *  8.050000E+03  0.000000E+00  0.000000E+00  0.000000E+00  2.500000E+02 -2.000000E+04 *
                    *  0.000000E+00  8.050000E+03  0.000000E+00 -2.500000E+02  0.000000E+00  1.832234E+04 *
                    *  0.000000E+00  0.000000E+00  8.050000E+03  2.000000E+04 -1.832234E+04  0.000000E+00 *
                    *  0.000000E+00 -2.500000E+02  2.000000E+04  2.512500E+05 -1.456625E+05 -4.346688E+03 *
                    *  2.500000E+02  0.000000E+00 -1.832234E+04 -1.456625E+05  9.476353E+05  0.000000E+00 *
                    * -2.000000E+04  1.832234E+04  0.000000E+00 -4.346688E+03  0.000000E+00  1.196385E+06 *
                                                                    S
                                         *  1.000000E+00  0.000000E+00  0.000000E+00 *
                                         *  0.000000E+00  1.000000E+00  0.000000E+00 *
                                         *  0.000000E+00  0.000000E+00  1.000000E+00 *
                            DIRECTION
                       MASS AXIS SYSTEM (S)     MASS              X-C.G.        Y-C.G.        Z-C.G.
                               X            8.050000E+03      0.000000E+00  2.484472E+00  3.105590E-02
                               Y            8.050000E+03      2.276067E+00  0.000000E+00  3.105590E-02
                               Z            8.050000E+03      2.276067E+00  2.484472E+00  0.000000E+00
                                                                   I(S)
                                         *  2.015528E+05  1.001412E+05  3.777671E+03 *
                                         *  1.001412E+05  9.059246E+05 -6.211180E+02 *
                                         *  3.777671E+03 -6.211180E+02  1.104993E+06 *
                                                                   I(Q)
                                         *  9.198783E+05                             *
                                         *                1.105014E+06               *
                                         *                              1.875778E+05 *
                                                                    Q
                                         *  1.380458E-01  4.794522E-03  9.904142E-01 *
                                         * -9.904069E-01 -5.532546E-03  1.380715E-01 *
                                         *  6.141498E-03 -9.999732E-01  3.984783E-03 *
```

Listing 7-17 Output for FSW Airplane in Antisymmetric Maneuvers (Continued)

```
 HALF-SPAN MODEL, STATIC ANTISYMMETRIC LOADING                                                     SUBCASE 1
N O N - D I M E N S I O N A L   S T A B I L I T Y   A N D   C O N T R O L   D E R I V A T I V E   C O E F F I C I E N T S
                                    MACH = 9.0000E-01                    Q = 1.2000E+03

           TRANSFORMATION FROM BASIC TO REFERENCE COORDINATES:
        { X }        [ -1.0000   0.0000   0.0000  ]  { X }        { 1.5000E+01 }
        { Y }    =   [  0.0000   1.0000   0.0000  ]  { Y }     +  { 0.0000E+00 }
        { Z }REF     [  0.0000   0.0000  -1.0000  ]  { Z }BAS     { 0.0000E+00 }

TRIM VARIABLE      COEFFICIENT              RIGID                         ELASTIC
                                  UNSPLINED        SPLINED        RESTRAINED      UNRESTRAINED
INTERCEPT             CX         0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                      CY         0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                      CZ         0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                      CMX        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                      CMY        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                      CMZ        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
SIDES                 CX         0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                      CY        -7.158447E-01   -7.158447E-01   -6.697496E-01   -7.259881E-01
                      CZ         0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                      CMX       -3.276105E-02   -3.276105E-02   -2.824561E-02   -2.706753E-02
                      CMY        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                      CMZ        2.592296E-01    2.592296E-01    2.425404E-01    2.630050E-01
YAW                   CX         0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                      CY         7.233017E-01    7.233017E-01    6.675829E-01    7.284513E-01
                      CZ         0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                      CMX        4.298554E-02    4.298554E-02    3.858262E-02    3.630278E-02
                      CMY        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                      CMZ       -2.775080E-01   -2.775080E-01   -2.572732E-01   -2.794162E-01
ROLL                  CX         0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                      CY         7.965025E-02    7.965025E-02    1.209624E-01    9.465972E-02
                      CZ         0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                      CMX       -4.184672E-01   -4.184672E-01   -5.070223E-01   -4.448231E-01
                      CMY        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                      CMZ       -2.605253E-02   -2.605253E-02   -4.053827E-02   -3.137640E-02
URDD2                 CX         0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                      CY         0.000000E+00    0.000000E+00    7.188179E-04    0.000000E+00
                      CZ         0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                      CMX        0.000000E+00    0.000000E+00    3.018458E-05    0.000000E+00
                      CMY        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                      CMZ        0.000000E+00    0.000000E+00   -2.601771E-04    0.000000E+00
URDD4                 CX         0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                      CY         0.000000E+00    0.000000E+00    2.021708E-03    0.000000E+00
                      CZ         0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                      CMX        0.000000E+00    0.000000E+00   -3.636955E-03    0.000000E+00
                      CMY        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                      CMZ        0.000000E+00    0.000000E+00   -7.117986E-04    0.000000E+00
URDD6                 CX         0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                      CY         0.000000E+00    0.000000E+00   -2.213319E-02    0.000000E+00
                      CZ         0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                      CMX        0.000000E+00    0.000000E+00   -9.981033E-04    0.000000E+00
                      CMY        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                      CMZ        0.000000E+00    0.000000E+00    8.080994E-03    0.000000E+00
AILERON               CX         0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                      CY        -1.082398E-01   -1.082398E-01   -1.142208E-01   -1.026430E-01
                      CZ         0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                      CMX        2.747558E-01    2.747558E-01    2.993375E-01    2.624515E-01
                      CMY        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                      CMZ        3.948340E-02    3.948340E-02    4.149461E-02    3.752508E-02
RUDDER                CX         0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                      CY         3.491402E-01    3.491402E-01    2.996780E-01    3.381154E-01
                      CZ         0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                      CMX        3.745069E-02    3.745069E-02    3.507515E-02    3.228768E-02
                      CMY        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                      CMZ       -1.706690E-01   -1.706690E-01   -1.525649E-01   -1.665393E-01
                                         INTERMEDIATE MATRIX ... HP

                                                    COLUMN       1
                              -1.678953E-01      6.878061E-03      -3.704068E-02
                                                COLUMN       2
                               1.784256E-01     -1.403152E-02       4.077220E-02
                                                COLUMN       3
                               3.155028E-02      4.272658E-01       6.442384E-03
                                                COLUMN       4
                              -5.583723E-03      1.048801E-05      -3.089367E-04
                                                COLUMN       5
                               3.735903E-04      2.427399E-02       5.812574E-05
                                                COLUMN       6
                               1.905984E-02     -2.519723E-05       1.645743E-02
                                                COLUMN       7
                              -3.053800E-02     -2.377972E-01      -6.602198E-03
                                                COLUMN       8
                               1.061561E-01     -1.858679E-02       2.767085E-02
```

Listing 7-17 Output for FSW Airplane in Antisymmetric Maneuvers (Continued)

```
                         A E R O S T A T I C   D A T A   R E C O V E R Y   O U T P U T   T A B L E
                                               AEROELASTIC TRIM VARIABLES
                                              TRIM VARIABLE    VALUE OF UX

                                                 SIDES        -1.823546E-02
                                                 YAW           0.000000E+00
                                                 ROLL          2.600432E-01
                                                 URDD2         0.000000E+00
                                                 URDD4         0.000000E+00
                                                 URDD6         0.000000E+00
                                                 AILERON       4.363320E-01
                                                 RUDDER        2.058725E-02

                         A E R O S T A T I C   D A T A   R E C O V E R Y   O U T P U T   T A B L E
                                    MACH = 9.000000E-01                Q = 1.200000E+03

                                                                                  AERODYNAMIC FORCES
AERODYNAMIC          AERODYNAMIC PRES.    AERODYNAMIC
       GRID    LABEL    COEFFICIENTS        PRESSURES           EXTERNAL ID  LABEL   NORMAL FORCES(T3)    MOMENTS(R2)
         1      LS     6.953958E-02       8.344750E+01              1000      LS     5.215469E+02       3.259668E+02
         2      LS     5.945857E-03       7.135028E+00              1001      LS     4.459393E+01       2.787120E+01
         3      LS     5.795575E-03       6.954690E+00              1002      LS     4.346682E+01       2.716676E+01
         4      LS     1.174454E-02       1.409345E+01              1003      LS     8.808403E+01       5.505252E+01
         5      LS     1.639822E-01       1.967786E+02              1004      LS     1.229866E+03       7.686666E+02
         6      LS     1.235348E-02       1.482418E+01              1005      LS     9.265111E+01       5.790694E+01
         7      LS     1.403922E-02       1.684706E+01              1006      LS     1.052941E+02       6.580883E+01
         8      LS     3.117443E-02       3.740932E+01              1007      LS     2.338093E+02       1.461302E+02
         9      LS     1.303585E-01       1.564302E+02              1100      LS     9.776888E+02       6.110555E+02
        10      LS     2.760369E-02       3.312442E+01              1101      LS     2.070276E+02       1.293923E+02
        11      LS    -2.503506E-02      -3.004207E+01              1102      LS    -1.877630E+02      -1.173519E+02
        12      LS    -5.044424E-03      -6.053308E+00              1103      LS    -3.783317E+01      -2.364573E+01
        13      LS     3.236980E-01       3.884376E+02              1104      LS     2.427735E+03       1.517334E+03
        14      LS    -2.888322E-02      -3.465986E+01              1105      LS    -2.166241E+02      -1.353901E+02
        15      LS    -6.597198E-02      -7.916637E+01              1106      LS    -4.947899E+02      -3.092437E+02
        16      LS    -4.027840E-02      -4.833408E+01              1107      LS    -3.020880E+02      -1.888050E+02
        17      LS     8.405132E-01       1.008616E+03              1108      LS     6.303850E+03       3.939906E+03
        18      LS    -3.487058E-03      -4.184470E+00              1109      LS    -2.615294E+01      -1.634559E+01
        19      LS    -1.656872E-01      -1.988246E+02              1110      LS    -1.242654E+03      -7.766587E+02
        20      LS    -1.130559E-01      -1.356671E+02              1111      LS    -8.479193E+02      -5.299496E+02
        21      LS     1.071735E+00       1.286082E+03              1112      LS     8.038014E+03       5.023759E+03
        22      LS     7.084341E-02       8.501208E+01              1113      LS     5.313256E+02       3.320785E+02
        23      LS    -3.196873E-01      -3.836247E+02              1114      LS    -2.397655E+03      -1.498534E+03
        24      LS    -3.142666E-01      -3.771199E+02              1115      LS    -2.357000E+03      -1.473125E+03
        25      LS     1.265719E+00       1.518862E+03              1116      LS     9.492890E+03       5.933056E+03
        26      LS     1.607172E-01       1.928606E+02              1117      LS     1.205379E+03       7.533619E+02
        27      LS    -3.866311E-01      -4.639574E+02              1118      LS    -2.899734E+03      -1.812333E+03
        28      LS    -1.454455E+00      -1.745346E+03              1119      LS    -1.090842E+04      -6.817759E+03
        29      LS     1.379795E+00       1.655755E+03              1120      LS     1.034847E+04       6.467791E+03
        30      LS     2.622649E-01       3.147179E+02              1121      LS     1.966987E+03       1.229367E+03
        31      LS    -3.446601E-01      -4.135921E+02              1122      LS    -2.584950E+03      -1.615594E+03
        32      LS    -1.637659E+00      -1.965191E+03              1123      LS    -1.228244E+04      -7.676525E+03
        33      LS     1.351922E+00       1.622306E+03              1124      LS     1.013941E+04       6.337134E+03
        34      LS     3.383746E-01       4.060495E+02              1125      LS     2.537810E+03       1.586131E+03
        35      LS    -2.112721E-01      -2.535266E+02              1126      LS    -1.584541E+03      -9.903381E+02
        36      LS    -1.607247E+00      -1.928696E+03              1127      LS    -1.205435E+04      -7.533970E+03
        37      LS     1.081452E+00       1.297742E+03              1128      LS     8.110890E+03       5.069306E+03
        38      LS     3.072515E-01       3.687018E+02              1129      LS     2.304386E+03       1.440241E+03
        39      LS    -1.031863E-02      -1.238236E+01              1130      LS    -7.738976E+01      -4.836860E+01
        40      LS    -1.353353E+00      -1.624024E+03              1131      LS    -1.015015E+04      -6.343843E+03
        41      LS    -1.499667E-01      -1.799601E+02              3100      LS    -1.124750E+03      -7.029689E+02
        42      LS    -1.346411E-02      -1.615693E+01              3101      LS    -1.009808E+02      -6.311300E+01
        43      LS     4.820608E-03       5.784729E+00              3102      LS     3.615456E+01       2.259660E+01
        44      LS     3.093417E-02       3.712100E+01              3103      LS     2.320063E+02       1.450040E+02
        45      LS    -7.612907E-02      -9.135488E+01              3104      LS    -5.709680E+02      -3.568550E+02
        46      LS    -3.047888E-02      -3.657465E+01              3105      LS    -2.285916E+02      -1.428698E+02
        47      LS     6.683536E-04       8.020244E-01              3106      LS     5.012652E+00       3.132908E+00
        48      LS     3.554533E-02       4.265440E+01              3107      LS     2.665900E+02       1.666188E+02
        49      LS     4.053394E-02       4.864073E+01              3108      LS     3.040046E+02       1.900029E+02
        50      LS    -2.538108E-02      -3.045730E+01              3109      LS    -1.903581E+02      -1.189738E+02
        51      LS    -6.749813E-03      -8.099775E+00              3110      LS    -5.062360E+01      -3.163975E+01
        52      LS     3.387398E-02       4.064878E+01              3111      LS     2.540549E+02       1.587843E+02
        53      LS     1.469073E-01       1.762888E+02              3112      LS     1.101805E+03       6.886282E+02
        54      LS    -4.172111E-03      -5.006533E+00              3113      LS    -3.129083E+01      -1.955677E+01
        55      LS    -1.380020E-02      -1.656024E+01              3114      LS    -1.035015E+02      -6.468845E+01
        56      LS     2.685823E-02       3.222987E+01              3115      LS     2.014367E+02       1.258979E+02

*** LABEL NOTATIONS:  LS = LIFTING SURFACE,   ZIB = Z INTERFERENCE BODY ELEMENT,   ZSB = Z SLENDER BODY ELEMENT,
                                              YIB = Y INTERFERENCE BODY ELEMENT,   YSB = Y SLENDER BODY ELEMENT.
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Listing 7-17 Output for FSW Airplane in Antisymmetric Maneuvers (Continued)

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 HALF-SPAN MODEL, STATIC ANTISYMMETRIC LOADING                                                    SUBCASE 2

N O N - D I M E N S I O N A L   S T A B I L I T Y   A N D   C O N T R O L   D E R I V A T I V E   C O E F F I C I E N T S

                                     MACH = 9.0000E-01                    Q = 1.2000E+03

          TRANSFORMATION FROM BASIC TO REFERENCE COORDINATES:
         { X }        [ -1.0000   0.0000   0.0000  ]  { X }        { 1.5000E+01 }
         { Y }    =   [  0.0000   1.0000   0.0000  ]  { Y }     +  { 0.0000E+00 }
         { Z }REF     [  0.0000   0.0000  -1.0000  ]  { Z }BAS     { 0.0000E+00 }

TRIM VARIABLE        COEFFICIENT              RIGID                           ELASTIC
                                     UNSPLINED      SPLINED          RESTRAINED     UNRESTRAINED
INTERCEPT              CX           0.000000E+00   0.000000E+00      0.000000E+00   0.000000E+00
                       CY           0.000000E+00   0.000000E+00      0.000000E+00   0.000000E+00
                       CZ           0.000000E+00   0.000000E+00      0.000000E+00   0.000000E+00
                       CMX          0.000000E+00   0.000000E+00      0.000000E+00   0.000000E+00
                       CMY          0.000000E+00   0.000000E+00      0.000000E+00   0.000000E+00
                       CMZ          0.000000E+00   0.000000E+00      0.000000E+00   0.000000E+00
SIDES                  CX           0.000000E+00   0.000000E+00      0.000000E+00   0.000000E+00
                       CY          -7.158447E-01  -7.158447E-01     -6.697496E-01  -7.259881E-01
                       CZ           0.000000E+00   0.000000E+00      0.000000E+00   0.000000E+00
                       CMX         -3.276105E-02  -3.276105E-02     -2.824561E-02  -2.706753E-02
                       CMY          0.000000E+00   0.000000E+00      0.000000E+00   0.000000E+00
                       CMZ          2.592296E-01   2.592296E-01      2.425404E-01   2.630050E-01
YAW                    CX           0.000000E+00   0.000000E+00      0.000000E+00   0.000000E+00
                       CY           7.233017E-01   7.233017E-01      6.675829E-01   7.284513E-01
                       CZ           0.000000E+00   0.000000E+00      0.000000E+00   0.000000E+00
                       CMX          4.298554E-02   4.298554E-02      3.858262E-02   3.630278E-02
                       CMY          0.000000E+00   0.000000E+00      0.000000E+00   0.000000E+00
                       CMZ         -2.775080E-01  -2.775080E-01     -2.572732E-01  -2.794162E-01
ROLL                   CX           0.000000E+00   0.000000E+00      0.000000E+00   0.000000E+00
                       CY           7.965025E-02   7.965025E-02      1.209624E-01   9.465972E-02
                       CZ           0.000000E+00   0.000000E+00      0.000000E+00   0.000000E+00
                       CMX         -4.184672E-01  -4.184672E-01     -5.070223E-01  -4.448231E-01
                       CMY          0.000000E+00   0.000000E+00      0.000000E+00   0.000000E+00
                       CMZ         -2.605253E-02  -2.605253E-02     -4.053827E-02  -3.137640E-02
URDD2                  CX           0.000000E+00   0.000000E+00      0.000000E+00   0.000000E+00
                       CY           0.000000E+00   0.000000E+00      7.188179E-04   0.000000E+00
                       CZ           0.000000E+00   0.000000E+00      0.000000E+00   0.000000E+00
                       CMX          0.000000E+00   0.000000E+00      3.018458E-05   0.000000E+00
                       CMY          0.000000E+00   0.000000E+00      0.000000E+00   0.000000E+00
                       CMZ          0.000000E+00   0.000000E+00     -2.601771E-04   0.000000E+00
URDD4                  CX           0.000000E+00   0.000000E+00      0.000000E+00   0.000000E+00
                       CY           0.000000E+00   0.000000E+00      2.021708E-03   0.000000E+00
                       CZ           0.000000E+00   0.000000E+00      0.000000E+00   0.000000E+00
                       CMX          0.000000E+00   0.000000E+00     -3.636955E-03   0.000000E+00
                       CMY          0.000000E+00   0.000000E+00      0.000000E+00   0.000000E+00
                       CMZ          0.000000E+00   0.000000E+00     -7.117986E-04   0.000000E+00
URDD6                  CX           0.000000E+00   0.000000E+00      0.000000E+00   0.000000E+00
                       CY           0.000000E+00   0.000000E+00     -2.213319E-02   0.000000E+00
                       CZ           0.000000E+00   0.000000E+00      0.000000E+00   0.000000E+00
                       CMX          0.000000E+00   0.000000E+00     -9.981033E-04   0.000000E+00
                       CMY          0.000000E+00   0.000000E+00      0.000000E+00   0.000000E+00
                       CMZ          0.000000E+00   0.000000E+00      8.080994E-03   0.000000E+00
AILERON                CX           0.000000E+00   0.000000E+00      0.000000E+00   0.000000E+00
                       CY          -1.082398E-01  -1.082398E-01     -1.142208E-01  -1.026430E-01
                       CZ           0.000000E+00   0.000000E+00      0.000000E+00   0.000000E+00
                       CMX          2.747558E-01   2.747558E-01      2.993375E-01   2.624515E-01
                       CMY          0.000000E+00   0.000000E+00      0.000000E+00   0.000000E+00
                       CMZ          3.948340E-02   3.948340E-02      4.149461E-02   3.752508E-02
RUDDER                 CX           0.000000E+00   0.000000E+00      0.000000E+00   0.000000E+00
                       CY           3.491402E-01   3.491402E-01      2.996780E-01   3.381154E-01
                       CZ           0.000000E+00   0.000000E+00      0.000000E+00   0.000000E+00
                       CMX          3.745069E-02   3.745069E-02      3.507515E-02   3.228768E-02
                       CMY          0.000000E+00   0.000000E+00      0.000000E+00   0.000000E+00
                       CMZ         -1.706690E-01  -1.706690E-01     -1.525649E-01  -1.665393E-01

                                         INTERMEDIATE MATRIX ... HP

                                                      COLUMN       1
                              -1.678953E-01       6.878061E-03      -3.704068E-02
                                                  COLUMN       2
                               1.784256E-01      -1.403152E-02       4.077220E-02
                                                  COLUMN       3
                               3.155028E-02       4.272658E-01       6.442384E-03
                                                  COLUMN       4
                              -5.583723E-03       1.048801E-05      -3.089367E-04
                                                  COLUMN       5
                               3.735903E-04       2.427399E-02       5.812574E-05
                                                  COLUMN       6
                               1.905984E-02      -2.519723E-05       1.645743E-02
                                                  COLUMN       7
                              -3.053800E-02      -2.377972E-01      -6.602198E-03
                                                  COLUMN       8
                               1.061561E-01      -1.858679E-02       2.767085E-02
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Listing 7-17 Output for FSW Airplane in Antisymmetric Maneuvers (Continued)

```
                         A E R O S T A T I C   D A T A   R E C O V E R Y   O U T P U T   T A B L E
                                                AEROELASTIC TRIM VARIABLES
                                               TRIM VARIABLE    VALUE OF UX

                                                  SIDES        -6.297442E-02
                                                  YAW           0.000000E+00
                                                  ROLL         -6.938894E-18
                                                  URDD2         0.000000E+00
                                                  URDD4         4.454218E+00
                                                  URDD6         0.000000E+00
                                                  AILERON       4.363320E-01
                                                  RUDDER        1.099768E-02

                         A E R O S T A T I C   D A T A   R E C O V E R Y   O U T P U T   T A B L E
                                    MACH = 9.000000E-01                Q = 1.200000E+03

                                                                                      AERODYNAMIC FORCES
AERODYNAMIC            AERODYNAMIC PRES.    AERODYNAMIC
       GRID   LABEL     COEFFICIENTS         PRESSURES          EXTERNAL ID  LABEL   NORMAL FORCES(T3)   MOMENTS(R2)
          1    LS      -4.527578E-04      -5.433094E-01                1000   LS      -3.395684E+00     -2.122302E+00
          2    LS      -5.883921E-04      -7.060705E-01                1001   LS      -4.412941E+00     -2.758088E+00
          3    LS      -1.556158E-03      -1.867390E+00                1002   LS      -1.167119E+01     -7.294493E+00
          4    LS      -4.046254E-03      -4.855505E+00                1003   LS      -3.034690E+01     -1.896681E+01
          5    LS      -1.045061E-03      -1.254073E+00                1004   LS      -7.837959E+00     -4.898724E+00
          6    LS      -1.345259E-03      -1.614311E+00                1005   LS      -1.008944E+01     -6.305902E+00
          7    LS      -3.623927E-03      -4.348712E+00                1006   LS      -2.717945E+01     -1.698716E+01
          8    LS      -1.008748E-02      -1.210498E+01                1007   LS      -7.565610E+01     -4.728506E+01
          9    LS      -6.170879E-02      -7.405054E+01                1100   LS      -4.628159E+02     -2.892599E+02
         10    LS      -3.456980E-02      -4.148376E+01                1101   LS      -2.592735E+02     -1.620459E+02
         11    LS      -2.932927E-02      -3.519513E+01                1102   LS      -2.199696E+02     -1.374810E+02
         12    LS      -5.151585E-03      -6.181902E+00                1103   LS      -3.863688E+01     -2.414805E+01
         13    LS      -1.462438E-01      -1.754925E+02                1104   LS      -1.096828E+03     -6.855176E+02
         14    LS      -1.315322E-01      -1.578387E+02                1105   LS      -9.864918E+02     -6.165573E+02
         15    LS      -9.292479E-02      -1.115097E+02                1106   LS      -6.969359E+02     -4.355850E+02
         16    LS      -3.714078E-02      -4.456893E+01                1107   LS      -2.785558E+02     -1.740974E+02
         17    LS      -1.884638E-01      -2.261566E+02                1108   LS      -1.413479E+03     -8.834241E+02
         18    LS      -2.229333E-01      -2.675199E+02                1109   LS      -1.672000E+03     -1.045000E+03
         19    LS      -2.293306E-01      -2.751968E+02                1110   LS      -1.719980E+03     -1.074987E+03
         20    LS      -1.156730E-01      -1.388076E+02                1111   LS      -8.675476E+02     -5.422172E+02
         21    LS      -1.648933E-01      -1.978720E+02                1112   LS      -1.236700E+03     -7.729375E+02
         22    LS      -2.805383E-01      -3.366459E+02                1113   LS      -2.104037E+03     -1.315023E+03
         23    LS      -4.403211E-01      -5.283854E+02                1114   LS      -3.302408E+03     -2.064005E+03
         24    LS      -3.472629E-01      -4.167155E+02                1115   LS      -2.604472E+03     -1.627795E+03
         25    LS      -1.096741E-01      -1.316089E+02                1116   LS      -8.225557E+02     -5.140973E+02
         26    LS      -2.777997E-01      -3.333597E+02                1117   LS      -2.083498E+03     -1.302186E+03
         27    LS      -5.641140E-01      -6.769368E+02                1118   LS      -4.230854E+03     -2.644284E+03
         28    LS      -1.514845E+00      -1.817814E+03                1119   LS      -1.136134E+04     -7.100837E+03
         29    LS      -4.686868E-02      -5.624242E+01                1120   LS      -3.515151E+02     -2.196969E+02
         30    LS      -2.175127E-01      -2.610153E+02                1121   LS      -1.631346E+03     -1.019591E+03
         31    LS      -5.620423E-01      -6.744507E+02                1122   LS      -4.215317E+03     -2.634573E+03
         32    LS      -1.723270E+00      -2.067924E+03                1123   LS      -1.292452E+04     -8.077828E+03
         33    LS       5.910913E-06       7.093096E-03                1124   LS       4.433185E-02      2.770741E-02
         34    LS      -1.246974E-01      -1.496369E+02                1125   LS      -9.352308E+02     -5.845192E+02
         35    LS      -4.382653E-01      -5.259183E+02                1126   LS      -3.286990E+03     -2.054368E+03
         36    LS      -1.709366E+00      -2.051239E+03                1127   LS      -1.282024E+04     -8.012652E+03
         37    LS       2.074346E-02       2.489215E+01                1128   LS       1.555759E+02      9.723495E+01
         38    LS      -4.688111E-02      -5.625734E+01                1129   LS      -3.516083E+02     -2.197552E+02
         39    LS      -1.931140E-01      -2.317368E+02                1130   LS      -1.448355E+03     -9.052219E+02
         40    LS      -1.447031E+00      -1.736438E+03                1131   LS      -1.085274E+04     -6.782960E+03
         41    LS       3.751652E-02       4.501982E+01                3100   LS       2.813739E+02      1.758587E+02
         42    LS       1.016392E-03       1.219671E+00                3101   LS       7.622944E+00      4.764340E+00
         43    LS       3.669803E-03       4.403764E+00                3102   LS       2.752353E+01      1.720220E+01
         44    LS       1.666951E-02       2.000341E+01                3103   LS       1.250213E+02      7.813833E+01
         45    LS       2.865467E-02       3.438560E+01                3104   LS       2.149100E+02      1.343188E+02
         46    LS       4.867668E-04       5.841202E-01                3105   LS       3.650751E+00      2.281719E+00
         47    LS       3.336146E-03       4.003375E+00                3106   LS       2.502109E+01      1.563818E+01
         48    LS       1.955092E-02       2.346111E+01                3107   LS       1.466319E+02      9.164496E+01
         49    LS       2.050808E-02       2.460970E+01                3108   LS       1.538106E+02      9.613164E+01
         50    LS      -8.179694E-03      -9.815634E+00                3109   LS      -6.134771E+01     -3.834232E+01
         51    LS      -5.041794E-04      -6.050153E-01                3110   LS      -3.781346E+00     -2.363341E+00
         52    LS       1.912964E-02       2.295556E+01                3111   LS       1.434723E+02      8.967017E+01
         53    LS       2.040322E-02       2.448386E+01                3112   LS       1.530241E+02      9.564007E+01
         54    LS      -1.897506E-02      -2.277007E+01                3113   LS      -1.423129E+02     -8.894558E+01
         55    LS      -9.822684E-03      -1.178722E+01                3114   LS      -7.367014E+01     -4.604383E+01
         56    LS       1.501389E-02       1.801666E+01                3115   LS       1.126041E+02      7.037759E+01

*** LABEL NOTATIONS:  LS = LIFTING SURFACE,  ZIB = Z INTERFERENCE BODY ELEMENT,  ZSB = Z SLENDER BODY ELEMENT,
                                             YIB = Y INTERFERENCE BODY ELEMENT,  YSB = Y SLENDER BODY ELEMENT.
```

Listing 7-17 Output for FSW Airplane in Antisymmetric Maneuvers (Continued)

```
      HALF-SPAN MODEL, STATIC ANTISYMMETRIC LOADING                                                                SUBCASE 1

                                                D I S P L A C E M E N T   V E C T O R

       POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
             90      G      0.0            0.0            0.0            0.0            0.0            0.0
             97      G      0.0            0.0            0.0            6.577028E-05   0.0            0.0
             98      G      0.0            0.0            0.0            6.577028E-05   0.0            0.0
             99      G     -7.856588E-22  -1.774797E-18   0.0           -6.577028E-05   0.0           -6.648222E-19
            100      G     -2.356976E-21   2.024627E-04   0.0           -3.288514E-04   0.0            6.073882E-05
            110      G     -3.036941E-04   2.712499E-05   1.130680E-02  -8.066081E-04   9.719276E-03   6.073882E-05
            111      G     -3.036941E-04  -1.247221E-04   3.560499E-02  -8.066081E-04   9.719276E-03   6.073882E-05
            112      G     -3.036941E-04   1.789720E-04  -1.299139E-02  -8.066081E-04   9.719276E-03   6.073882E-05
            120      G     -9.110823E-04  -3.235506E-04   9.708962E-02  -1.389569E-03   2.424943E-02   6.073882E-05
            121      G     -9.110823E-04  -4.753977E-04   1.577132E-01  -1.389569E-03   2.424943E-02   6.073882E-05
            122      G     -9.110823E-04  -1.717036E-04   3.646603E-02  -1.389569E-03   2.424943E-02   6.073882E-05
            310      G     -2.356976E-21   1.986964E-03   1.969445E-36  -1.676225E-04  -1.046196E-36   3.296157E-04
            311      G     -2.356976E-21   1.162925E-03  -6.460454E-37  -1.676225E-04  -1.046196E-36   3.296157E-04
            312      G     -2.356976E-21   2.811003E-03   4.584934E-36  -1.676225E-04  -1.046196E-36   3.296157E-04

      HALF-SPAN MODEL, STATIC ANTISYMMETRIC LOADING                                                                SUBCASE 2

                                                D I S P L A C E M E N T   V E C T O R

       POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
             90      G      0.0            0.0            0.0            0.0            0.0            0.0
             97      G      0.0            0.0            0.0           -4.769856E-06   0.0            0.0
             98      G      0.0            0.0            0.0           -4.769856E-06   0.0            0.0
             99      G      2.399211E-19  -2.583937E-19   0.0            4.769856E-06   0.0           -9.856156E-20
            100      G      7.197632E-19   3.694714E-05   0.0            2.384928E-05   0.0            1.108414E-05
            110      G     -5.542071E-05   4.950001E-06   6.249369E-03   1.289376E-04   4.107157E-03   1.108414E-05
            111      G     -5.542071E-05  -2.276035E-05   1.651726E-02   1.289376E-04   4.107157E-03   1.108414E-05
            112      G     -5.542071E-05   3.266035E-05  -4.018524E-03   1.289376E-04   4.107157E-03   1.108414E-05
            120      G     -1.662621E-04  -5.904429E-05   5.385996E-02   2.887151E-04   1.153925E-02   1.108414E-05
            121      G     -1.662621E-04  -8.675465E-05   8.270809E-02   2.887151E-04   1.153925E-02   1.108414E-05
            122      G     -1.662621E-04  -3.133394E-05   2.501183E-02   2.887151E-04   1.153925E-02   1.108414E-05
            310      G      7.197632E-19  -3.824723E-05   9.339349E-35   1.167260E-05  -4.451331E-35  -4.227443E-06
            311      G      7.197632E-19  -2.767862E-05  -1.788979E-35   1.167260E-05  -4.451331E-35  -4.227443E-06
            312      G      7.197632E-19  -4.881584E-05   2.046768E-34   1.167260E-05  -4.451331E-35  -4.227443E-06

      HALF-SPAN MODEL, STATIC ANTISYMMETRIC LOADING                                                                SUBCASE 1

                                   F O R C E S   I N   B A R   E L E M E N T S         ( C B A R )
  ELEMENT         BEND-MOMENT END-A            BEND-MOMENT END-B                - SHEAR -                 AXIAL
    ID.         PLANE 1       PLANE 2        PLANE 1       PLANE 2        PLANE 1       PLANE 2           FORCE          TORQUE
      100     0.0            3.456485E-11   0.0            2.287579E-11   0.0            2.337814E-12  -4.525395E-13  -3.551595E+03
      101     0.0            0.0            0.0            0.0            0.0            0.0            0.0            2.842171E-14
      102     0.0            0.0            0.0            0.0            0.0            0.0            0.0           -3.551595E+03
      103     0.0            2.284248E-11   0.0           -2.623917E+03   0.0            2.623917E+02  -4.525395E-13  -7.103189E+03
      110     1.977727E+05   1.818989E-11   1.872521E+05   5.062471E-12   1.822220E+03   2.273737E-12   3.637979E-12   3.748168E+05
      120     1.317888E+05   1.637090E-11   1.609371E+05   1.111993E-11  -2.524316E+03   4.547474E-13  -9.094947E-13   2.787513E+05
      310     4.102077E-29   6.507272E+03   4.584849E-30  -3.918364E+03   6.310887E-30   1.805773E+03   9.466331E-30   6.786811E+03

      HALF-SPAN MODEL, STATIC ANTISYMMETRIC LOADING                                                                SUBCASE 2

                                   F O R C E S   I N   B A R   E L E M E N T S         ( C B A R )
  ELEMENT         BEND-MOMENT END-A            BEND-MOMENT END-B                - SHEAR -                 AXIAL
    ID.         PLANE 1       PLANE 2        PLANE 1       PLANE 2        PLANE 1       PLANE 2           FORCE          TORQUE
      100     0.0            4.879410E-12   0.0            3.636308E-12   0.0            2.486204E-13   1.381945E-10   2.575722E+02
      101     0.0            0.0            0.0            0.0            0.0            0.0            0.0            3.552714E-15
      102     0.0            0.0            0.0            0.0            0.0            0.0            0.0            2.575722E+02
      103     0.0            3.646647E-12   0.0           -4.788349E+02   0.0            4.788349E+01   1.381945E-10   5.151445E+02
      110     9.012888E+04   1.822855E-09   9.559770E+04   1.179611E-09  -9.472266E+02   1.114131E-10  -8.344614E-11   1.517433E+05
      120     8.744491E+04   1.153694E-09   7.945616E+04   4.836493E-11   6.918464E+02   9.572432E-11  -4.183676E-11   1.376222E+05
      310     1.817536E-27  -1.683244E+03  -5.143632E-28   2.418574E+02   4.038968E-28  -3.334373E+02   1.615587E-27  -4.189096E+02
```

Listing 7-17 Output for FSW Airplane in Antisymmetric Maneuvers (Continued)

```
   HALF-SPAN MODEL, STATIC ANTISYMMETRIC LOADING                                                          SUBCASE 1

                                S T R E S S E S   I N   B A R   E L E M E N T S         ( C B A R )
 ELEMENT        SA1            SA2            SA3            SA4            AXIAL          SA-MAX         SA-MIN      M.S.-T
   ID.          SB1            SB2            SB3            SB4            STRESS         SB-MAX         SB-MIN      M.S.-C
     100  -2.304324E-10   2.304324E-10  -2.304324E-10   2.304324E-10  -2.262697E-13   2.302061E-10  -2.306586E-10
          -1.525052E-10   1.525052E-10  -1.525052E-10   1.525052E-10                  1.522790E-10  -1.527315E-10
     101   0.0            0.0            0.0            0.0            0.0            0.0            0.0
           0.0            0.0            0.0            0.0                           0.0            0.0
     102   0.0            0.0            0.0            0.0            0.0            0.0            0.0
           0.0            0.0            0.0            0.0                           0.0            0.0
     103  -1.522832E-10   1.522832E-10  -1.522832E-10   1.522832E-10  -2.262697E-13   1.520569E-10  -1.525095E-10
           1.749278E+04  -1.749278E+04   1.749278E+04  -1.749278E+04                  1.749278E+04  -1.749278E+04
     110  -5.695858E+05  -5.695858E+05   5.695858E+05   5.695858E+05   2.425319E-12   5.695858E+05  -5.695858E+05
          -5.392864E+05  -5.392864E+05   5.392864E+05   5.392864E+05                  5.392864E+05  -5.392864E+05
     120  -3.795520E+05  -3.795520E+05   3.795520E+05   3.795520E+05  -6.063298E-13   3.795520E+05  -3.795520E+05
          -4.634991E+05  -4.634991E+05   4.634991E+05   4.634991E+05                  4.634991E+05  -4.634991E+05
     310  -1.952182E+04   1.952182E+04  -1.952182E+04   1.952182E+04   1.262177E-29   1.952182E+04  -1.952182E+04
           1.175509E+04  -1.175509E+04   1.175509E+04  -1.175509E+04                  1.175509E+04  -1.175509E+04

   HALF-SPAN MODEL, STATIC ANTISYMMETRIC LOADING                                                          SUBCASE 2

                                S T R E S S E S   I N   B A R   E L E M E N T S         ( C B A R )
 ELEMENT        SA1            SA2            SA3            SA4            AXIAL          SA-MAX         SA-MIN      M.S.-T
   ID.          SB1            SB2            SB3            SB4            STRESS         SB-MAX         SB-MIN      M.S.-C
     100  -3.252940E-11   3.252940E-11  -3.252940E-11   3.252940E-11   6.909727E-11   1.016267E-10   3.656787E-11
          -2.424206E-11   2.424206E-11  -2.424206E-11   2.424206E-11                  9.333933E-11   4.485521E-11
     101   0.0            0.0            0.0            0.0            0.0            0.0            0.0
           0.0            0.0            0.0            0.0                           0.0            0.0
     102   0.0            0.0            0.0            0.0            0.0            0.0            0.0
           0.0            0.0            0.0            0.0                           0.0            0.0
     103  -2.431098E-11   2.431098E-11  -2.431098E-11   2.431098E-11   6.909727E-11   9.340825E-11   4.478629E-11
           3.192233E+03  -3.192233E+03   3.192233E+03  -3.192233E+03                  3.192233E+03  -3.192233E+03
     110  -2.595713E+05  -2.595713E+05   2.595713E+05   2.595713E+05  -5.563076E-11   2.595713E+05  -2.595713E+05
          -2.753215E+05  -2.753215E+05   2.753215E+05   2.753215E+05                  2.753215E+05  -2.753215E+05
     120  -2.518415E+05  -2.518415E+05   2.518415E+05   2.518415E+05  -2.789117E-11   2.518415E+05  -2.518415E+05
          -2.288339E+05  -2.288339E+05   2.288339E+05   2.288339E+05                  2.288339E+05  -2.288339E+05
     310   5.049731E+03  -5.049731E+03   5.049731E+03  -5.049731E+03   2.154116E-27   5.049731E+03  -5.049731E+03
          -7.255722E+02   7.255722E+02  -7.255722E+02   7.255722E+02                  7.255722E+02  -7.255722E+02
```

FSW Airplane in Unsymmetric Maneuvers

This example demonstrates the use of the MSC Nastran static aeroelastic capability to predict the loads produced in unsymmetric maneuvers. A full-span model is necessary to analyze the loads and stresses of an unsymmetric vehicle or of a symmetric vehicle if its maneuvers are unsymmetric. The example here is a full-span model of the FSW airplane considered in symmetric flight in Example HA144A (p. 200) and in antisymmetric maneuvers in Example HA144D (p. 279). It is only necessary to add the left wing, aileron, and the left side of the canard to the antisymmetric model, which already contains the right side as well as the fin and rudder, and to double the for the stiffnesses and weights fuselage and fin.

The left wing is added to the Bulk Data Section beginning with GRIDs 210 through 212 and 220 through 222 which are connected to the left wing elastic axis by RBARs 211, 212, 221, and 222. The left wing elastic axis consists of CBARs 210 and 220 and has the same properties as the right wing. The left wing masses are defined by CONM2s 211, 212, 221, and 222. The left canard structure is described by fuselage degrees of freedom (as is the right canard) and needs no new data.

The aerodynamic reference geometry and symmetry are modified on the AEROS entry due to the full-span model: CORD2R 100 is the NACA reference coordinate system; the reference chord is 10.0 ft; the reference span is 40.0 ft; the reference area becomes 400.0 ft^2; and SYMXZ = 0 for no symmetry. The left wing aerodynamics are added by CAERO1 2100 with its spline SPLINE2 2601 along its axis on CORD2R 20 and are connected to the left wing grid points using SET1 2100. The left canard aerodynamics are added by CAERO1 2000 along with SPLINE2 1501 and SET1 1000.

The left aileron boxes are listed on AELIST 2100, and the total aileron system is given by AESURF 517, which includes both left and right ailerons. The left aileron hinge line is specified on CORD2R 210 and gives a positive aileron deflection with trailing edge down, which is the opposite from the right aileron. The left canard boxes are also added to AESURF 505 using AELIST 2000. CORD2R 1 defines the positive rotation (leading edge up) for both sides since the left and right canard rotate together.

The symmetric and antisymmetric controls (AESURF entries) and motions (AESTAT entries) are combined in this example and result in three control rotations:

- canard, δ_e = ELEV, aileron
- δ_a = AILERON
- rudder, δ_r, = RUDDER

Ten motions also result:

- angle of attack, α = ANGLEA
- sideslip angle, β = SIDES
- pitch rate, $q\bar{c}/2V$ = PITCH
- roll rate, $pb/2V$ = ROLL
- yaw rate, $rb/2V$ = YAW
- vertical load factor, $n_z = \ddot{z}/g$ = URDD3
- side load factor, $n_y = \ddot{y}/g$ = URDD2
- pitch acceleration, $\dot{q}/g$ = URDD5
- roll acceleration $\dot{p}/g$ = URDD4
- yaw acceleration, $\dot{r}/g$ = URDD6

In anticipation of using this model in later aeroelastic design sensitivity and optimization studies, the model is divided between basic data that will not be involved in the optimization, and design data that will be involved. The basic information is contained in the input file fswtwo.dat (see Listing 7-18), which includes all of the configuration Bulk Data entries for GRIDs, the fuselage structure and weight, and the aerodynamic model. The remaining configuration entries are contained in the Bulk Data Section as shown in Listing 7-19, which includes the right wing, left wing, and fin structure, as well as the weight data.

Symmetrical Cruise

One symmetrical and four unsymmetrical flight conditions are demonstrated in this example. The symmetrical condition is included for comparison with Example HA144A (p. 200). All of the flight conditions are at high speed at sea level with $\bar{q} = 1200\ \text{psf}$ and a Mach number $m = 0.9$. With a speed of sound at sea level of 1117 ft/sec, the $m = 0.9$ airspeed is $V = 0.9 \times 1117 = 1005\ \text{ft/s}$. For level flight, the vertical load factor is $n_z = \text{URDD3} = -1.0$ in the NACA frame of reference (z is positive downward), the pitch rate is zero, the aileron and rudder rotations are zero, and the five accelerations are all zero. With eight trim variables specified, the remaining five are determined: angle of attack, sideslip angle, canard rotation, and roll and yaw rates. The symmetry of the flight condition should result in computed zeroes for the antisymmetric trim variables.

Steady Rolling Pullout

The second flight condition is the first unsymmetrical maneuver. TRIM 2 is a high-speed steady rolling pullout with a vertical load factor of $n_z = \text{URDD3} = -4.8$. Corresponding to the load factor is the steady pitch rate of

$$q = (-n_z - 1)g/V = (4.8 - 1.0)32.174/1005.0 = 0.12165 \text{ rad/sec}$$

so $q\bar{c}/2V = \text{PITCH} = 0.12165 \times 10.0/2 \times 1005.0 = 0.000605$. The aileron deflection is $\delta_a = \text{AILERON} = 25.0 \text{ deg} = 0.436332 \text{ rad}$. The steady yaw rate $rb/2V = \text{YAW} = 0.0$, and the lateral acceleration and roll, pitch, and yaw accelerations are zero: URDD2 = URDD4 = URDD5 = URDD6 = 0.0. The five variables to be determined are angle of attack, canard rotation, sideslip angle, rudder rotation, and roll rate. The second unsymmetrical maneuver is TRIM 3, which is a high-speed pullout with an abrupt roll; therefore, the trim variables are the same as on the TRIM 2 entry except that the roll rate $pb/2V$ ROLL $= 0.0$ instead of the roll acceleration being zero. The five variables to be determined are now the angle of attack, canard rotation, sideslip angle, rudder rotation, and acceleration in roll.

Snap Roll

The third unsymmetrical flight condition is TRIM 4, which is a transition from level flight into a snap-roll with maximum rotations of canard and rudder that are assumed at $\delta_e = \text{ELEV} = 25.0 \text{ deg} = 0.436332 \text{ rad} = \delta_r = \text{RUDDER}$. From SUBCASE 1 the initial angle of attack is $\alpha = \text{ANGLEA} = 0.0031512 \text{ rad} = 0.18 \text{ deg}$. The variables that are assumed to be zero at the beginning of the maneuver are aileron rotation, sideslip angle, and pitch, roll, and yaw rates. The five resulting accelerations will be found.

Steady Climbing Turn

The last unsymmetrical maneuver, TRIM 5, is a steady climbing turn. This type of maneuver is thoroughly analyzed by Etkin (1972, pp. 423-428 [Reference 14]). A climb rate of $R/C = 1500.0$ ft/min and a horizontal turning rate of $\omega = 3.0$ deg/sec are assumed along with the Mach number $m = 0.9$ at sea level assumed in the previous subcases. The turn coordinator gyro instrument actually measures the yaw rate r but is calibrated to give the standard turning rate of 3.0 deg/sec at the bank angle that would be flown in a level turn at cruise speed. The angular rates in a steady turn with a small climb angle θ as given in Etkin [1972, Eqs. (10.4,5) [Reference 14]] are

$$\begin{Bmatrix} p \\ q \\ r \end{Bmatrix} = \begin{Bmatrix} -\theta \\ sin\phi \\ cos\phi \end{Bmatrix}\omega$$

and the bank angle ϕ is given by Etkin [1972, Eqs. (10.4,7) [Reference 14]] as

$$tan\phi = \frac{\omega V}{g}$$

For this subcase $\omega = 3.0 \text{ deg/sec} = 0.052360 \text{ rad/sec}$; therefore, the bank angle becomes

$$tan\phi = \frac{0.052360 \times 1005}{32.174} = 1.635538$$

or $\phi = 58.56 \text{ deg}$. The pitch and yaw rates become

$$q = 0.044672 \text{ rad/sec} \text{ and } r = 0.027313 \text{ rad/sec}$$

The roll rate requires the pitch angle in the climb, which is found from the vertical speed and the angle of attack. The angle of attack in the climb can be estimated from the load factor [Etkin (1972, Eqs. (10.4,9)) [Reference 14]].

$$n_z = -sec\phi = -1.9170 = \text{URDD3}$$

and the level flight trim angle of attack from SUBCASE 1 of $\alpha = 0.003152$ to be

$$\alpha = 0.003152 \times 1.9170 = 0.006042 \text{ rad}$$

The angle of climb is

$$\gamma = \frac{R/C}{V} = \frac{1500/60}{1005} = 0.024876 \text{ rad}$$

Thus, the pitch angle is

$$\theta = \gamma + \alpha = 0.030918 \text{ rad}$$

Finally, the roll rate becomes

$$p = -\theta\omega = -0.001619 \text{ rad/sec}$$

The dimensionless angular rates then become

$$\frac{pb}{2V} = \text{ROLL} = -0.00003222$$

$$\frac{q\bar{c}}{2V} = \text{PITCH} = 0.0002222$$

$$\frac{rb}{2V} = \text{YAW} = 0.0005435$$

The remaining input parameters are the zero accelerations: URDD2 = URDD4 = URDD5 = URDD6 = 0.0. The five trim variables to be determined are the angle of attack, the canard rotation, the sideslip angle, the aileron rotation, and the rudder rotation. The ENDDATA entry completes the Bulk Data Section. The trim data for the five flight conditions are also shown in Listing 7-19.

Case Control Commands

The first three entries of the Case Control Section list the headers that appear at the top of every page of output and at the bottom of every plot output. The ECHO = BOTH command specifies that both the unsorted and sorted Bulk Data entries be printed in the output. The SPC command is required by the corresponding Bulk Data entries. The DISP command specifies that all displacements be printed. The STRESS, FORCE, AEROF, and APRES commands request that all stress, force, aerodynamic force, and pressure data be printed. The pairs of SUBCASE and TRIM commands are also required by the corresponding Bulk Data entries; the sets of output data are identified according to the subcase number, which may be different from the TRIM command ID.

The remaining commands in the Case Control Section specify output plot parameters. The OUTPUT(PLOT) command delimits the output request designated by its argument, in this case, the structure plotter. The PLOTTER NASTRAN command invokes the NASTRAN plotter routine. The SET 1 command specifies that all deflections be plotted. The FIND command requests that the computer program determine the scale and origin for the set to be plotted. Then the PLOT command invokes the plot routine and specifies that the static deformations be plotted and outlined. The BEGIN BULK command completes the Case Control Section.

The first statement in the Executive Control Section is ID MSC, HA144E, which is the identification of this example. The next statement TIME 5 restricts the CPU time to 5.0 minutes of computing. SOL 144 calls for the Static Aeroelastic Response DMAP sequence. Finally, the CEND statement completes the Executive Control Section.

Output

The Executive Control and Case Control data are shown in Listing 7-19. The sorted Bulk Data entries are presented in Listing 7-20, and the output results follow in Listing 7-21.

The output data to be discussed begin with the OUTPUT FROM GRID POINT WEIGHT GENERATOR, which gives the inertial characteristics of the full-span model, including its gross weight of 16,100 lbs.

The next output table is the NON-DIMENSIONAL STABILITY AND CONTROL DERIVATIVES. The coefficients for longitudinal and lateral-directional motions are preceded by the transformation from the basic to the reference coordinates; then the rigid and elastic coefficients are tabulated. The rigid coefficients include those calculated with and without the spline as a check on the splining. The elastic coefficients are tabulated for both the restrained and unrestrained conditions. The rigid coefficients can be compared with the longitudinal coefficients of Example HA144A, and the lateral-directional coefficients of Example HA144D, and they agree exactly. The elastic coefficients can also be compared with the same previous examples: the longitudinal restrained aerodynamic coefficients agree exactly, but the inertial coefficients differ slightly because Example HA144A does not include the fin weight. The lateral-directional coefficients agree very closely because Example HA144D has the same gross weight.

The INTERMEDIATE MATRIX... HP follows with the mean axis deflections and rotations. Note that the printed format is the transpose of the matrix. The first, third, and fifth rows of values shown beginning with the sixth column can be compared with the three rows given in the lateral-directional case of Example HA144D; the second and fourth rows of values shown beginning in the first column can be compared closely (because of the different gross weights) with the two rows and five columns given in the longitudinal case of Example HA144A.

The remaining output includes the AEROSTATIC DATA RECOVERY OUTPUT TABLE which contains the trim solutions (AEROELASTIC TRIM VARIABLES) and aerodynamic pressure coefficients, pressures, and loads (NORMAL FORCES and MOMENTS on each aerodynamic box). The aeroelastic coefficients are output for each subcase but are only shown in Listing 7-21 for the first subcase. The standard MSC Nastran output of displacements, element forces, and element stresses follows the aeroelastic output.

SUBCASE 1 determines the trim variables in level flight and is followed by the aerodynamic loads. The angle of attack is $\alpha = 0.003151 \text{ rad} = 0.18 \text{ deg}$ and canard incidence is $\delta_e = 0.01725 \text{ rad} = 0.99 \text{ deg}$. The sideslip angle and the yaw and roll rates are computed zeroes.

The SUBCASE 2 trim solution and aerodynamic loads for the rolling pullout are shown next. The pullout at 4.8 g's results in an angle of attack $\alpha = 0.01370 \text{ rad} = 0.78 \text{ deg}$ and canard incidence $\delta_e = 0.08540 \text{ rad} = 4.89 \text{ deg}$. The steady roll rate achieved with the aileron deflection δ_a of 25 deg is $pb/2V = 0.2600$ and is accompanied by a sideslip angle $\beta = -0.01824 \text{ rad} = -1.05 \text{ deg}$ and rudder rotation $\delta_r = 0.02059 \text{ rad} = 1.18 \text{ deg}$. The positive rudder rotation is required because the lifting surface theory (Vortex-Lattice method) predicts a proverse yawing moment from the ailerons.

The SUBCASE 3 trim solution and aerodynamic loads are then shown for the maneuver of a pullout with an abrupt roll. The pullout results in the same angle of attack and canard incidence as before, but the abrupt aileron input now results in a roll acceleration $\dot{p}/g = 4.454 \text{ rad/ft}$ or $\dot{p} = 8211 \text{ deg/s}^2$ with a sideslip angle $\beta = -0.06297 \text{ rad} = -3.61 \text{ deg}$ and rudder rotation $\delta_r = 0.01100 \text{ rad} = 0.63 \text{ deg}$.

The SUBCASE 4 trim solution and aerodynamic loads are shown next for the snap-roll entry. The resulting accelerations are a vertical load factor of $n_z = -8.660 \text{ g's}$, a lateral load factor of $n_y = 3.127 \text{ g's}$, a pitching acceleration of $\dot{q}/g = 0.5768\ \text{rad/ft}$ or $\dot{q} = 1063\ \text{deg/s}^2$, a rolling acceleration of $\dot{p}/g = 0.5235\ \text{rad/ft}$ or $\dot{p} = 965\ \text{deg/s}^2$, and a yawing acceleration of $\dot{r}/g = -0.5281\ \text{rad/ft}$ or $\dot{r} = -974\ \text{deg/s}^2$.

The SUBCASE 5 trim solution and aerodynamic loads for the climbing turn are shown last. The angle of attack is $\alpha = 0.005519\ \text{rad} = 0.32\ \text{deg}$, and the canard angle is $\delta_e = 0.03402\ \text{rad} = 1.94\ \text{deg}$. The input data for this case required a pitch angle to determine the roll rate. The pitch angle was estimated from the sum of the climb angle, known from the vertical speed, and the angle of attack, which was estimated from the load factor in the turn and the previously determined angle of attack in level flight. The input roll rate was based on a pitch angle calculation that assumed an angle of attack of $0.006042\ \text{rad} = 0.35\ \text{deg}$. The assumed angle of attack is close to the value just obtained from the climbing turn solution. Another iteration could be made to bring these numbers into even closer agreement, but it does not appear necessary. Only small control surface rotations and sideslip angle are required to coordinate the example turn: aileron, $\delta_a = -0.00005857\ \text{rad} = -0.0034\ \text{deg}$, rudder, $\delta_r = -0.0001941\ \text{rad} = -0.011\ \text{deg}$, and sideslip angle, $\beta = 0.0004591\ \text{rad} = 0.026\ \text{deg}$.

Data Recovery

Following the SUBCASE 5 trim solution and aerodynamic loads are the outputs for the five subcases for displacements, forces in the BAR elements, and the stresses in the BAR elements. The stresses may appear to be high, but recall that their units are psf. The differences between the stresses in the right and left sides are of interest in the unsymmetrical maneuvers. The higher levels will, of course, be the critical ones for the purpose of aircraft design.

Listing 7-18 fswtwo.dat Input File

```
$*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
$                                                                          $
$        THE ANNOTATIONS IN THIS INPUT DECK ARE INTENDED TO                $
$        EXPLAIN THE DATA ON THE CARD IMAGES FOR THIS SPECIFIC             $
$        EXAMPLE WITHOUT REFERENCE TO THE VARIOUS MANUALS WHERE            $
$        MORE GENERAL DESCRIPTIONS WILL BE FOUND.                          $
$                                                                          $
$*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
$                                                                          $
$                       * * * STRUCTURAL DATA * * *                        $
$                                                                          $
$                            (LB-FT-SEC SYSTEM)                            $
$                                                                          $
$                          * * GRID GEOMETRY * *                           $
$                                                                          $
$        GRID  90 - 100 (T3) FUSELAGE POINTS                               $
$        GRID 110 - 122 (T3) WING POINTS                                   $
$        GRID 310 - 312 (t3) FIN POINTS                                    $
$                                                                          $
$                            * FUSELAGE GRID *                             $
$                                                                          $
$        THE GRID ENTRY DEFINES THE LOCATION OF A STRUCTURAL GRID          $
$        POINT.  LISTED ARE ITS COORDINATE SYSTEM ID, ITS LOCATION,        $
$        THE ID OF THE COORDINATE SYSTEM IN WHICH ITS DISPLACEMENTS        $
$        ARE DEFINED, ITS PERMANENT SINGLE-POINT CONSTRAINTS AND           $
$        ITS ASSOCIATED SUPERELEMENT ID.                                   $
$                                                                          $
$       ID      CP      X1      X2      X3     CD      PS      SEID
GRID    90              15.     0.      0.
GRID    97              0.      0.      0.
GRID    98              10.     0.      0.
GRID    99              20.     0.      0.
GRID    100             30.     0.      0.
$                                                                          $
$                         * RIGHT WING GRID *                              $
$                                                                          $
$       ID      CP      X1     X2       X3     CD      PS      SEID
GRID    111             24.61325 +5.    0.
GRID    110             27.11325 +5.    0.
GRID    112             29.61325 +5.    0.
GRID    121             18.83975+15.    0.
GRID    120             21.33975+15.    0.
GRID    122             23.83975+15.    0.
$                                                                          $
$                         * LEFT WING GRID *                               $
$                                                                          $
$       ID     CP       X1     X2       X3     CD      PS      SEID
GRID    211             24.61325 -5.    0.
GRID    210             27.11325 -5.    0.
GRID    212             29.61325 -5.    0.
GRID    221             18.83975-15.    0.
GRID    220             21.33975-15.    0.
GRID    222             23.83975-15.    0.
$                                                                          $
$                             * FIN GRID *                                 $
$                                                                          $
GRID    310                 32.88675+0.         5.
GRID    311                 30.38675+0.         5.
GRID    312                 35.38675+0.         5.
$                                                                          $
$                * * STRUCTURAL STIFFNESS PROPERTIES * *                   $
$                                                                          $
$                        * FUSELAGE STRUCTURE *                            $
$                                                                          $
$        THE CBAR ENTRY DEFINES A SIMPLE BEAM ELEMENT.  LISTED ARE         $
$        ITS PROPERTY ENTRY ID, THE TWO GRID POINTS JOINED BY THE          $
$        BEAM AND COMPONENTS OF A VECTOR FROM THE FIRST POINT.             $
$        THIS VECTOR DEFINES THE DIRECTION OF THE STRUCTURAL DE-           $
$        FLECTION OF THE POINT AND ITS POSITIVE SENSE.                     $
$                                                                          $
$       EID     PID     GA      GB    X1,GO    X2      X3
CBAR    101     100     97      98      0.      0.      1.
CBAR    102     100     98      90      0.      0.      1.
CBAR    103     100     90      99      0.      0.      1.
CBAR    104     100     99      100     0.      0.      1.
```

Listing 7-18 fswtwo.dat Input File (Continued)

```
$                                                                         $
$        THE PBAR ENTRY DEFINES GEOMETRIC PROPERTIES OF THE BEAM.         $
$        LISTED ARE ITS ASSOCIATED MATERIAL ENTRY ID, ITS CROSS SEC-      $
$        TIONAL AREA, AREA MOMENTS OF INERTIA, TORSIONAL MOMENT           $
$        OF INERTIA AND NON-STRUCTURAL MASS PER UNIT AREA.  THE           $
$        OPTIONAL CONTINUATION ENTRY CONTAINS STRESS RECOVERY             $
$        COEFFICIENTS, that is, Y,Z COORDINATES WHERE STRESSES ARE           $
$        TO BE COMPUTED.  K1 AND K2 ARE AREA FACTORS FOR SHEAR            $
$        STIFFNESS (DEFAULT IS BLANK; THEN SHEAR STIFFNESS IS             $
$        INFINITE, that is, SHEAR FLEXIBILITY IS ZERO.  I12 IS THE           $
$        AREA PRODUCT OF INERTIA.                                         $
$                                                                         $
$       PID     MID    A        I1      I2      J       NSM
PBAR    100    1       4.0     .347222  .30     1.0                     +PB1F
$       C1      C2      D1      D2      E1      E2      F1      F2
+PB1F   1.0     1.0     1.0     -1.0    -1.0    1.0     -1.0    -1.0    +PB2F
$       K1      K2      I12
+PB2F                   0.0
$                                                                         $
$        THE MAT1 ENTRY DEFINES THE MATERIAL PROPERTIES.  LISTED          $
$        ARE ITS ID, ITS ELASTIC MODULUS, SHEAR MODULUS, POISSONS         $
$        RATIO, MASS DENSITY, TEMPERATURE EXPANSION COEFFICIENT,          $
$        REFERENCE TEMPERATURE AND A STRUCTURAL DAMPING COEFFICIENT.      $
$                                                                         $
$MAT1   MID    E       G     NU     RHO     A     TREF     GE     +MT
MAT1    1      1.44+9  5.40+8        0.0
$
$
$                 * * MASS AND INERTIA PROPERTIES * *                     $
$                                                                         $
$                          * FUSELAGE MASSES *                            $
$                                                                         $
$        THE CONM2 ENTRY DEFINES A CONCENTRATED MASS.  LISTED ARE         $
$        ITS ID, GRID LOCATION, COORDINATE SYSTEM TO LOCATE THE           $
$        CENTER OF GRAVITY, THE MASS VALUE AND THE LOCATION OF            $
$        THE CENTER OF GRAVITY RELATIVE TO THE GRID LOCATION.             $
$                                                                         $
$       EID     G       CID     M        X1      X2      X3
CONM2   97      97      0       3000.0
CONM2   98      98      0       3000.0
CONM2   99      99      0       3000.0
CONM2   100     100     0       3000.0
$                                                                         $
$                    * * STRUCTURAL PARAMETERS * *                        $
$                                                                         $
$        THE PARAM,GRDPNT,XX ENTRY CAUSES THE GRID POINT WEIGHT           $
$        GENERATOR TO BE EXECUTED USING GRID POINT XX AS THE REF-         $
$        ERENCE POINT.  THEN THE INERTIA MATRIX, THE TRANSFER MATRIX      $
$        FROM BASIC TO PRINCIPAL AXES AND OTHER PERTINENT INERTIA         $
$        DATA ARE PRINTED.                                                $
$                                                                         $
PARAM   GRDPNT  90
$                                                                         $
$        THE PARAM,WTMASS,GINV CAUSES ALL THE STRUCTURAL MASSES AND       $
$        MASS DENSITIES TO BE MULTIPLIED BY GINV (that is, BY ONE OVER       $
$        THE ACCELERATION OF GRAVITY).  THE DYNAMIC PRESSURE SUPPLIED     $
$        FOR AERODYNAMIC FORCE CALCULATIONS WILL NOT BE MULTIPLIED        $
$        BY GINV.                                                         $
$                                                                         $
PARAM   WTMASS  .031081
$
$        THE PARAM,AUNITS,GINV PERMITS THE ACCELERATIONS ON THE TRIM
$        ENTRY TO BE SPECIFIED IN UNITS OF LOAD FACTOR (that is, IN G'S)
$
PARAM   AUNITS  .031081
$                                                                         $
$                    * * STRUCTURAL CONSTRAINTS * *                       $
$                                                                         $
$        THE SPC1 ENTRY CONSTRAINS THE LISTED GRID POINTS IN THE          $
$        SPECIFIED DOF COMPONENTS.                                        $
$                                                                         $
$       SID     C       G1      G2    G3      G4
SPC1    1       1       90
$                                                                         $
$        THE SUPORT ENTRY IDENTIFIES A GRID POINT OR A SCALAR POINT       $
$        AND SPECIFIES THE DOF COMPONENTS IN WHICH THE USER DESIRES       $
$        REACTIONS TO BE APPLIED TO PREVENT RIGID BODY MOTION.  IT        $
$        THUS INVOKES THE SOLUTION OF THE BALANCE EQUATIONS TO DETER-     $
$        MINE THE REACTIONS.  IN THE STATIC AEROELASTIC SOLUTION          $
$        THE DOF COMPONENTS MUST BE CONSISTENT WITH THE UNDEFINED         $
$        VARIABLES ON THE TRIM ENTRIES                                    $
```

Listing 7-18 fswtwo.dat Input File (Continued)

```
$                                                                      $
$       ID      C
SUPORT  90      23456
$                                                                      $
$        THE OMIT1 ENTRY IDENTIFIES GRID POINTS TO BE OMITTED FROM     $
$        THE REMAINDER OF THE ANALYSIS.                                $
$                                                                      $
$       ID      G       G       G      G
OMIT1   4       110     120     210    220     310
$                                                                      $
$                     * * * AERODYNAMIC DATA * * *                     $
$                                                                      $
$                          (LB-FT-SEC SYSTEM)                          $
$                                                                      $
$                       * * ELEMENT GEOMETRY * *                       $
$                                                                      $
$        THE AEROS ENTRY IS UNIQUE TO THE STATIC AEROELASTICITY        $
$        SOLUTION, SOL144. ACSID IDENTIFIES THE AERO COORDINATE        $
$        SYSTEM, RCSID IDENTIFIES THE REFERENCE COORDINATE SYS-        $
$        TEM FOR RIGID BODY MOTION.  REFC IS THE REFERENCE CHORD.      $
$        REFB IS THE REFERENCE SPAN.  REFS IS THE REFERENCE WING       $
$        AREA.  SYMXZ AND SYMXY ARE SYMMETRY KEYS.                     $
$                                                                      $
$      ACSID    RCSID   REFC    REFB    REFS    SYMXZ   SYMXY
AEROS   1       100     10.0    40.0    400.0
$                                                                      $
$        THIS CORD2R ENTRY DEFINES THE AERO COORDINATE SYSTEM          $
$        FLAGGED BY THE AEROS ENTRY.  THE ORIGIN IS AT THE CANARD      $
$        QUARTER CHORD.  LISTED ARE THE ORIGIN, A POINT ALONG THE      $
$        Z AXIS AND A POINT IN THE X-Z PLANE, ALL IN THE RID           $
$        COORDINATE SYSTEM.                                            $
$                                                                      $
$       CID     RID     A1      A2      A3      B1      B2      B3
CORD2R  1       0       12.5    0.      0.      12.5    0.      10.     +CRD1
$       C1      C2      C3
+CRD1   20.     0.      0.
$                                                                      $
$        THIS CORD2R ENTRY DEFINES THE NACA COORDINATE SYSTEM TO       $
$        WHICH ALL THE STABILITY DERIVATIVES AND TRIM CONDITIONS       $
$        WILL BE REFERENCED.                                           $
$                                                                      $
$       CID     RID     A1      A2      A3      B1      B2      B3
CORD2R  100     0       15.0    0.0     0.0     15.0    0.0     -10.0   +CRD100
$       C1      C2      C3
+CRD100 0.0     0.0     0.0
$                                                                      $
$                                                                      $
$                      * WING AERODYNAMIC MODEL *                      $
$                                                                      $
$        THE CAERO1 ENTRY IS USED FOR DOUBLET-LATTICE AERODYNAMICS.    $
$        LISTED ARE ITS PAERO ENTRY ID AND THE COORDINATE SYSTEM       $
$        FOR LOCATING THE INBOARD AND OUTBOARD LEADING EDGE POINTS     $
$        (1 AND 4).  NSPAN AND NCHORD, OR LSPAN AND LCHORD, ARE        $
$        USED TO PARTITION THE WING INTO AERODYNAMIC PANELS,           $
$        THE FORMER FOR UNIFORMLY SPACED PANELS AND THE LATTER         $
$        FOR NON-UNIFORMLY SPACED PANELS.  IGID IS THE ID OF ITS       $
$        ASSOCIATED INTERFERENCE GROUP.  THE CONTINUATION ENTRY        $
$        DEFINES POINTS 1 AND 4, THE ROOT CHORD AND TIP CHORD.         $
$        THE BOXES FORMED BY THE GRID LINES WILL BE NUMBERED           $
$        BEGINNING WITH EID SO CHOOSE A NUMBER THAT IS UNIQUE,         $
$        AND IS GREATER THAN ALL STRUCTURAL GRID, SCALAR AND           $
$        EXTRA POINT IDS.                                              $
$                                                                      $
$                         * RIGHT WING *
$       EID     PID     CP      NSPAN   NCHORD  LSPAN   LCHORD    IGID
CAERO1  1100    1000            8       4                         1     +CARW
$      ( FWD LEFT POINT  )     CHORD  ( FWD RIGHT POINT   )      CHORD
$       X1      Y1      Z1      X12     X4        Y4    Z4        X14
+CARW   25.     0.      0.      10.     13.45299+20.    0.        10      .
$                                                                      $
$        THE PAERO1 ENTRY IS REQUIRED EVEN THOUGH IT IS NON-FUNCTIONAL $
$        (BECAUSE THERE ARE NO ASSOCIATED BODIES IN THIS EXAMPLE).     $
$                                                                      $
$       PID     B1      B2      B3     B4      B5      B6
PAERO1  1000
$                                                                      $
$                          * LEFT WING *
CAERO1  2100    1000            8      4                          1     +CALW
+CALW    13.45299-20.    0.   10.     25.     0.      0.      10.
```

Listing 7-18 fswtwo.dat Input File (Continued)

```
$                                                                       $
$                      * CANARD AERODYNAMIC MODEL *                     $
$                                                                       $
$                            * RIGHT SIDE *
CAERO1   1000     1000          2      4                    1        +CARC
+CARC    10.      0.      0.   10.    10.     5.     0.       10.
$                                                                       $
$                            * LEFT SIDE *
CAERO1   2000     1000          2      4                    1        +CALC
+CALC    10.      -5.     0.   10.    10.     0.     0.       10.
$                                                                       $
$                       * FIN AERODYNAMIC MODEL *                       $
$                                                                       $
CAERO1   3100     1000          4      4                    1        +CA1FI
+CA1FI   30.7735  0.      10    10.    25.    0.     0.       10.
$                                                                       $
$                * * SPLINE FIT ON THE LIFTING SURFACES * *             $
$                                                                       $
$                     * BEAM SPLINE FIT ON THE WING *                   $
$                                                                       $
$        THE SPLINE2 ENTRY SPECIFIES A BEAM SPLINE FOR INTERPOLAT-      $
$        ION OVER THE REGION OF THE CAERO ENTRY (ID1 AND ID2 ARE        $
$        THE FIRST AND LAST BOXES IN THIS REGION).  SETG REFERS         $
$        TO A SET1 ENTRY WHERE THE STRUCTURAL GRID POINTS ARE           $
$        DEFINED.  DZ AND DTOR ARE SMOOTHING CONSTANTS FOR LINEAR       $
$        ATTACHMENT AND TORSIONAL FLEXIBILITIES.  CID IDENTIFIES        $
$        THE CORD2R ENTRY THAT DEFINES THE SPLINE AXIS.  DTHX AND       $
$        DTHY ARE ROTATIONAL ATTACHMENT FLEXIBILITIES (-1. SPECIFIES    $
$        NO ATTACHMENT).                                                $
$                                                                       $
$                            * RIGHT WING *                             $
$        EID      CAERO    ID1     ID2    SETG    DZ    DTOR    CID
SPLINE2  1601     1100     1100   1131    1100    0.    1.      2        +SPRW
$        DTHX     DTHY
+SPRW    -1.      -1.
$                                                                       $
$        THE SET1 ENTRY DEFINES THE SETS OF STRUCTURAL GRID POINTS      $
$        TO BE USED BY THE BEAM SPLINE FOR INTERPOLATION.               $
$                                                                       $
$        SID      G1       G2      G3     G4
SET1     1100     99       100     111    112     121    122
$                                                                       $
$                           * LEFT WING *                               $
$        EID     CAERO    ID1     ID2     SETG    DZ     DTOR    CID
SPLINE2  2601    2100     2100   2131     2100    0.     1.      20      +SPLW
$        DTHX     DTHY
+SPLW    -1.      -1.
$                                                                       $
$        THE SET1 ENTRY DEFINES THE SETS OF STRUCTURAL GRID POINTS      $
$        TO BE USED BY THE BEAM SPLINE FOR INTERPOLATION.               $
$                                                                       $
$        SID     G1       G2      G3      G4
SET1     2100    99       100     211     212     221     222
$                                                                       $
$                   * BEAM SPLINE FIT ON THE CANARD *                   $
$                                                                       $
$                            * RIGHT SIDE *                             $
SPLINE2  1501    1000    1000    1007    1000    0.      1.     1        +SPRC
+SPRC    1.      -1.
$                                                                       $
SET1     1000    98       99
$                                                                       $
$                            * LEFT SIDE *                              $
SPLINE2  2501    2000    2000   2007     1000    0.      1.     1        +SPLC
+SPLC    1.      -1.
$                                                                       $
$                     * BEAM SPLINE FIT ON THE FIN *                    $
$                                                                       $
SPLINE2  3100    3100    3100   3115     3100    0.      1.     300      +SP2FI
+SP2FI   -1.     -1.
$                                                                       $
SET1     3100    99       100    311      312
$                                                                       $
$        THE CORD2R ENTRY DEFINES THE COORDINATE SYSTEM IN WHICH THE    $
$        BEAM SPLINE EXTENDS ALONG THE WING Y-AXIS.  IT LISTS THE       $
$        ORIGIN, A POINT ALONG THE Z-AXIS AND A POINT IN THE X-Z        $
$        PLANE.                                                         $
```

Listing 7-18 fswtwo.dat Input File (Continued)

```
$                       * RIGHT WING SPLINE AXIS *                      $
$                                                                       $
$       CID     CS      A1      A2      A3      B1      B2      B3
CORD2R  2       0       30.     0.      0.      30.     0.      10.     +CRD2RW
$       C1      C2      C3
+CRD2RW 38.66025+5.0    0.
$                                                                       $
$                       * LEFT WING SPLINE AXIS *                       $
$                                                                       $
$       CID     CS      A1      A2      A3      B1      B2      B3
CORD2R  20      0       30.     0.      0.      30.     0.      10.     +CRD2LW
$       C1      C2      C3
+CRD2LW 38.66025-5.0    0.
$                                                                       $
$                          * FIN SPLINE AXIS *                          $
$                                                                       $
CORD2R  300     0       30.0     0.      0.     30.0    10.0     0.     +CRD2FI
+CRD2FI 20.0    0.0     5.7735
$                                                                       $
$                  * CONTROL SURFACE DEFINITION *                       $
$                                                                       $
$       THE AESURF ENTRY DEFINES AN AERODYNAMIC CONTROL SURFACE.        $
$       LISTED ARE THE ALPHANUMERIC NAME OF THE SURFACE, THE ID         $
$       OF A COORDINATE SYSTEM THAT DEFINES THE HINGE LINE AND          $
$       THE ID OF AN AELIST ENTRY.                                      $
$                                                                       $
$       ID      LABEL   CID1   ALID1  CID2     ALID2
AESURF  505     ELEV    1      1000   1        2000
AESURF  517     AILERON 110    1100   210      2100
AESURF  518     RUDDER  301    3000
$                                                                       $
$       THE AELIST ENTRY LISTS AERODYNAMIC BOXES THAT LIE ON THE        $
$       CONTROL SURFACE.                                                $
$                                                                       $
$       SID     E1      E2     E3      ETC
AELIST  1000    1000    THRU   1007
AELIST  2000    2000    THRU   2007
AELIST  1100    1119    1123   1127    1131
AELIST  2100    2103    2107   2111    2115
AELIST  3000    3103    3107   3111    3115
$                                                                       $
$                    * CONTROL SURFACE HINGE LINES *                    $
$                                                                       $
$                              * CANARD *                               $
$     THE COORDINATE SYSTEM, CORD2R,1, REFERENCED BY THE AEROS ENTRY    $
$      IS THE CANARD HINGE LINE, AND NEEDS NO FURTHER DEFINITION        $
$                                                                       $
$                           * RIGHT AILERON *                           $
CORD2R  110     0       26.7265   10.0   0.   26.7265   10.0   -10.     +CRD2RA
+CRD2RA 36.7265 15.7735 0.
$                                                                       $
$                            * LEFT AILERON *                           $
CORD2R  210     0       26.7265  -10.0  0.    26.7265   -10.0  10.0     +CRD2LA
+CRD2LA 36.7265 -15.7735 0.
$                                                                       $
$                               * RUDDER *                              $
CORD2R  301     0       32.5      0.     0.    32.5      -10.   0.0     +CRD2R
+CRD2R  22.5    0.      5.7735
$                                                                       $
$                       * * AERODYNAMIC DOFS * *                        $
$                                                                       $
$       THE AESTAT ENTRY LISTS TRIM VARIABLES USED TO SPECIFY           $
$       RIGID BODY MOTIONS.  THESE AND THE CONTROL SURFACE              $
$       ROTATIONS MAKE UP THE VARIABLES IN THE EQUATIONS OF             $
$       MOTION.                                                         $
$                                                                       $
$       ID      LABEL
AESTAT  501     ANGLEA
AESTAT  502     PITCH
AESTAT  503     URDD3
AESTAT  504     URDD5
AESTAT  511     SIDES
AESTAT  512     YAW
AESTAT  513     ROLL
AESTAT  514     URDD2
AESTAT  515     URDD4
AESTAT  516     URDD6
```

Listing 7-19 Input Files for FSW Airplane in Unsymmetric Maneuvers

```
   N A S T R A N   E X E C U T I V E   C O N T R O L   D E C K   E C H O


ID MSC, HA144E
$$$$$$$$  HANDBOOK FOR AEROELASTIC ANALYSIS EXAMPLE HA144E      $$$$$$$$
$                                                                      $
$       MODEL DESCRIPTION        FULL SPAN 30 DEG FWD SWEPT WING       $
$                                WITH AILERON, CANARD AND AFT SWEPT    $
$                                VERTICAL FIN AND RUDDER.              $
$                                BAR MODEL WITH DUMBBELL MASSES.       $
$                                                                      $
$       SOLUTION                 QUASI-STEADY AEROELASTIC ANALYSIS     $
$                                USING DOUBLET-LATTICE METHOD          $
$                                AERODYNAMICS AT MACH NO. 0.9.         $
$                                                                      $
$       OUTPUT                   PLOTS OF THE STICK MODEL AND AERO     $
$                                GRID, LISTS OF RESTRAINED AND         $
$                                UNRESTRAINED SYMMETRIC AND ANTI-      $
$                                SYMMETRIC STABILITY DERIVATIVES,      $
$                                AERODYNAMIC FORCES AND PRESSURES      $
$                                PLUS STRESSES AND DEFLECTIONS FOR     $
$                                LEVEL FLIGHT AND SEVERAL UNSYM-       $
$                                METRICAL MANUEVERS.                   $
$                                                                      $
$                                                                      $
$$$$$$$$                                                        $$$$$$$$
TIME 5 $ CPU TIME IN MINUTES
SOL 144 $ STATIC AERO
CEND


EXAMPLE HA144E: 30 DEG FWD SWEPT WING WITH 3 CONTROLS                                 PAGE     2
 UNSYMMETRIC FLIGHT CONDITIONS, DOUBLET-LATTICE AERO
 FULL-SPAN MODEL
                               C A S E   C O N T R O L   D E C K   E C H O
            CARD
            COUNT
             1      TITLE = EXAMPLE HA144E: 30 DEG FWD SWEPT WING WITH 3 CONTROLS
             2      SUBTI = UNSYMMETRIC FLIGHT CONDITIONS, DOUBLET-LATTICE AERO
             3      LABEL = FULL-SPAN MODEL
             4        ECHO    = BOTH
             5        SPC     = 1   $ SYMMETRIC CONSTRAINTS
             6        SET 1   = 1 THRU 999999
             7        DISP    = 1   $ PRINT ALL DISPLACEMENTS
             8        STRESS  = ALL $ PRINT ALL STRESSES
             9        FORCE   = ALL $ PRINT ALL FORCES
            10        AEROF   = ALL $ PRINT ALL AERODYNAMIC FORCES
            11        APRES   = ALL $ PRINT ALL AERODYNAMIC PRESSURES
            12      SUBCASE 1
            13        TRIM = 1      $ HIGH SPEED LEVEL FLIGHT
            14      SUBCASE 2
            15        TRIM = 2      $ HIGH SPEED ROLLING PULLOUT
            16      SUBCASE 3
            17        TRIM = 3      $ HIGH SPEED PULLOUT WITH ABRUPT ROLL
            18      SUBCASE 4
            19        TRIM = 4      $ HIGH SPEED SNAP-ROLL ENTRY
            20      SUBCASE 5
            21        TRIM = 5      $ HIGH SPEED CLIMBING TURN
            22      OUTPUT(PLOT)
            23        PLOTTER = NASTRAN
            24        SET 1 = ALL
            25        FIND SCALE, ORIGIN 1,SET 1
            26        PLOT SET 1
            27        PLOT STATIC DEFORMATION 0, ORIGIN 1, SET 1, OUTLINE
            28      BEGIN BULK
```

Listing 7-19 Input Files for FSW Airplane in Unsymmetric Maneuvers (Continued)

```
EXAMPLE HA144E: 30 DEG FWD SWEPT WING WITH 3 CONTROLS                                                      PAGE     3
 UNSYMMETRIC FLIGHT CONDITIONS, DOUBLET-LATTICE AERO
 FULL-SPAN MODEL
                                        I N P U T   B U L K   D A T A   D E C K   E C H O

                         .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                         $
                         $
                         $*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
                         $                                                                    $
                         $        THE ANNOTATIONS IN THIS INPUT DECK ARE INTENDED TO          $
                         $        EXPLAIN THE DATA ON THE CARD IMAGES FOR THIS SPECIFIC       $
                         $        EXAMPLE WITHOUT REFERENCE TO THE VARIOUS MANUALS WHERE      $
                         $        MORE GENERAL DESCRIPTIONS WILL BE FOUND.                    $
                         $                                                                    $
                         $*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
                         INCLUDE FSW_TWO.DAT                                                  $
                         $                                                                    $
                         $                       * RIGHT WING STRUCTURE *                     $
                         $                                                                    $
                         $       EID     PID     GA      GB      X1,GO   X2      X3
                         CBAR    110     101     100     110     0.      0.      1.
                         CBAR    120     101     110     120     0.      0.      1.
                         $                                                                    $
                         $        THE RBAR ENTRY DEFINES A RIGID BAR.  LISTED ARE THE GRID    $
                         $        POINTS AT EACH END AND THE DEPENDENT AND INDEPENDENT DOFS   $
                         $        AT EACH END.  THE NUMBER OF INDEPENDENT DOFS AT THE TWO     $
                         $        ENDS MUST EQUAL SIX.  BY DEFAULT THOSE NOT DECLARED INDE-   $
                         $        PENDENT ARE MADE DEPENDENT.                                 $
                         $                                                                    $
                         $       EID     GA      GB      CNA     CNB     CMA     CMB
                         RBAR    111     110     111     123456
                         RBAR    112     110     112     123456
                         RBAR    121     120     121     123456
                         RBAR    122     120     122     123456
                         $                                                                    $
                         $       PID     MID     A       I1      I2      J       NSM
                         PBAR    101     2       1.5     0.173611+2.0    0.462963             +PB1W
                         $       C1      C2      D1      D2      E1      E2      F1      F2
                         +PB1W   0.5     3.0     0.5     -3.0    -0.5    3.0     -0.5    -3.0 +PB2W
                         $       K1      K2      I12
                         +PB2W                   0.0
                         $                                                                    $
                         $
                         $                       * LEFT WING STRUCTURE *                      $
                         $                                                                    $
                         $       EID     PID     GA      GB      X1,GO   X2      X3
                         CBAR    210     101     100     210     0.      0.      1.
                         CBAR    220     101     210     220     0.      0.      1.
                         $
                         RBAR    211     210     211     123456
                         RBAR    212     210     212     123456
                         RBAR    221     220     221     123456
                         RBAR    222     220     222     123456
                         $                                                                    $
                         $                          * FIN STRUCTURE *                         $
                         $                                                                    $
                         CBAR    310     101     100     310     0.      0.      1.
                         $                                                                    $
                         RBAR    311     310     311     123456
                         RBAR    312     310     312     123456
                         $                                                                    $
                         $        THE MAT1 ENTRY DEFINES THE MATERIAL PROPERTIES.  LISTED     $
                         $        ARE ITS ID, ITS ELASTIC MODULUS, SHEAR MODULUS, POISSONS    $
                         $        RATIO, MASS DENSITY, TEMPERATURE EXPANSION COEFFICIENT,     $
                         $        REFERENCE TEMPERATURE AND A STRUCTURAL DAMPING COEFFICIENT. $
                         $                                                                    $
                         $       MID     E       G       NU      RHO     A       TREF    GE
                         MAT1    2       1.44+9  5.40+8
                         $                                                                    $
                         $                        * RIGHT WING MASSES *                       $
                         $                                                                    $
                         CONM2   111     111     0       600.0
                         CONM2   112     112     0       400.0
                         CONM2   121     121     0       600.0
                         CONM2   122     122     0       400.0
```

Listing 7-19 Input Files for FSW Airplane in Unsymmetric Maneuvers (Continued)

```
$                                                                       $
$                        * LEFT WING MASSES *                           $
$                                                                       $
CONM2   211     211     0       600.0
CONM2   212     212     0       400.0
CONM2   221     221     0       600.0
CONM2   222     222     0       400.0
$                                                                       $
$                           * FIN MASSES *                              $
$                                                                       $
CONM2   311     311     0       60.0
CONM2   312     312     0       40.0
$                                                                       $
$                       * * TRIM CONDITIONS * *                         $
$                                                                       $
$        THE TRIM ENTRY SPECIFIES CONSTRAINTS FOR THE TRIM VARIABLES    $
$        LISTED ON THE AESTAT AND AESURF ENTRIES.  LISTED ARE ITS ID,   $
$        THE MACH NUMBER, DYNAMIC PRESSURE AND PAIRS OF TRIM VARI-      $
$        ABLES AND THEIR CONSTRAINED VALUES.  THOSE THAT ARE NOT        $
$        HELD FIXED MUST BE CONSTRAINED BY REACTION FORCES STIPU-       $
$        LATED ON THE SUPORT ENTRY.  SEE SECTION 3.5.3 OF THE THEO-     $
$        RETICAL MANUAL FOR MORE DETAILS.                               $
$                                                                       $
$        TRIM CONDITION 1: LEVEL FLIGHT AT HIGH DYNAMIC PRESSURE        $
$                                                                       $
TRIM    1       0.9     1200.0   PITCH  0.      URDD3   -1.0            +TR1A
+TR1A   URDD5   0.      AILERON 0.      RUDDER  0.      URDD2   0.      +TR1B
+TR1B   URDD4   0.      URDD6   0.
$                                                                       $
$        TRIM CONDITION 2: HIGH SPEED ROLLING PULLOUT                   $
$                                                                       $
TRIM    2       0.9     1200.0  PITCH   6.0499-4URDD3   -4.8            +TR2A
+TR2A   URDD5   0.      AILERON .436332 YAW     0.      URDD2   0.      +TR2B
+TR2B   URDD4   0.      URDD6   0.
$                                                                       $
$        TRIM CONDITION 3: HIGH SPEED PULLUP WITH ABRUPT ROLL           $
$                                                                       $
TRIM    3       0.9     1200.0   PITCH  6.0499-4URDD3   -4.8            +TR3A
+TR3A   URDD5   0.      AILERON .436332 ROLL    0.      YAW     0.      +TR3B
+TR3B   URDD2   0.      URDD6   0.
$                                                                       $
$        TRIM CONDITION 4: HIGH SPEED ENTRY INTO SNAP-ROLL              $
$                                                                       $
TRIM    4       0.9     1200.0  ANGLEA  .0031512ELEV    .436332         +TR4A
+TR4A   PITCH   0.      SIDES   0.      ROLL    0.      YAW     0.      +TR4B
+TR4B   AILERON 0.      RUDDER  .436332
$                                                                       $
$        TRIM CONDITION 5: HIGH SPEED CLIMBING TURN                     $
$                                                                       $
TRIM    5       0.9     1200.0  PITCH   .2222-3 URDD3   -1.9170         +TR5A
+TR5A   URDD5   0.      YAW     .5435-3 ROLL    -.3222-4URDD2   0.      +TR5B
+TR5B   URDD4   0.      URDD6   0.
$                                                                       $
$                                * * *                                  $
ENDDATA
INPUT BULK DATA CARD COUNT =     502
```

Listing 7-20 Sorted Bulk Data Entries for FSW Airplane in Unsymmetric Maneuvers

```
EXAMPLE HA144E: 30 DEG FWD SWEPT WING WITH 3 CONTROLS                                                      PAGE    14
 UNSYMMETRIC FLIGHT CONDITIONS, DOUBLET-LATTICE AERO
 FULL-SPAN MODEL
                                         S O R T E D   B U L K   D A T A   E C H O
            CARD
            COUNT        .  1  ..  2  ..  3  ..  4  ..  5  ..  6  ..  7  ..  8  ..  9  ..  10  .
               1-        AELIST  1000    1000    THRU    1007
               2-        AELIST  1100    1119    1123    1127    1131
               3-        AELIST  2000    2000    THRU    2007
               4-        AELIST  2100    2103    2107    2111    2115
               5-        AELIST  3000    3103    3107    3111    3115
               6-        AEROS   1       100     10.0    40.0    400.0
               7-        AESTAT  501     ANGLEA
               8-        AESTAT  502     PITCH
               9-        AESTAT  503     URDD3
              10-        AESTAT  504     URDD5
              11-        AESTAT  511     SIDES
              12-        AESTAT  512     YAW
              13-        AESTAT  513     ROLL
              14-        AESTAT  514     URDD2
              15-        AESTAT  515     URDD4
              16-        AESTAT  516     URDD6
              17-        AESURF  505     ELEV    1       1000    1       2000
              18-        AESURF  517     AILERON 110     1100    210     2100
              19-        AESURF  518     RUDDER  301     3000
              20-        CAERO1  1000    1000            2       4                       1       +CARC
              21-        +CARC   10.     0.      0.      10.     10.     5.      0.      10.
              22-        CAERO1  1100    1000            8       4                       1       +CARW
              23-        +CARW   25.     0.      0.      10.     13.45299+20.    0.      10.
              24-        CAERO1  2000    1000            2       4                       1       +CALC
              25-        +CALC   10.     -5.     0.      10.     10.     0.      0.      10.
              26-        CAERO1  2100    1000            8       4                       1       +CALW
              27-        +CALW   13.45299-20.    0.      10.     25.     0.      0.      10.
              28-        CAERO1  3100    1000            4       4                       1       +CA1FI
              29-        +CA1FI  30.7735 0.      10.     10.     25.     0.      0.      10.
              30-        CBAR    101     100     97      98      0.      0.      1.
              31-        CBAR    102     100     98      90      0.      0.      1.
              32-        CBAR    103     100     90      99      0.      0.      1.
              33-        CBAR    104     100     99      100     0.      0.      1.
              34-        CBAR    110     101     100     110     0.      0.      1.
              35-        CBAR    120     101     110     120     0.      0.      1.
              36-        CBAR    210     101     100     210     0.      0.      1.
              37-        CBAR    220     101     210     220     0.      0.      1.
              38-        CBAR    310     101     100     310     0.      0.      1.
              39-        CONM2   97      97      0       3000.0
              40-        CONM2   98      98      0       3000.0
              41-        CONM2   99      99      0       3000.0
              42-        CONM2   100     100     0       3000.0
              43-        CONM2   111     111     0       600.0
              44-        CONM2   112     112     0       400.0
              45-        CONM2   121     121     0       600.0
              46-        CONM2   122     122     0       400.0
              47-        CONM2   211     211     0       600.0
              48-        CONM2   212     212     0       400.0
              49-        CONM2   221     221     0       600.0
              50-        CONM2   222     222     0       400.0
              51-        CONM2   311     311     0       60.0
              52-        CONM2   312     312     0       40.0
              53-        CORD2R  1       0       12.5    0.      0.      12.5    0.      10.     +CRD1
              54-        +CRD1   20.     0.      0.
              55-        CORD2R  2       0       30.     0.      0.      30.     0.      10.     +CRD2RW
              56-        +CRD2RW 38.66025+5.0    0.
              57-        CORD2R  20      0       30.     0.      0.      30.     0.      10.     +CRD2LW
              58-        +CRD2LW 38.66025-5.0    0.
              59-        CORD2R  100     0       15.0    0.0     0.0     15.0    0.0     -10.0   +CRD100
              60-        +CRD100 0.0     0.0     0.0
              61-        CORD2R  110     0       26.7265 10.0    0.      26.7265 10.0    -10.0   +CRD2RA
              62-        +CRD2RA 36.7265 15.7735 0.
              63-        CORD2R  210     0       26.7265 -10.0   0.      26.7265 -10.0   10.0    +CRD2LA
              64-        +CRD2LA 36.7265 -15.77350.
              65-        CORD2R  300     0       30.0    0.      0.      30.0    10.0    0.      +CRD2FI
              66-        +CRD2FI 20.0    0.0     5.7735
              67-        CORD2R  301     0       32.5    0.      0.      32.5    -10.    0.0     +CRD2R
              68-        +CRD2R  22.5    0.      5.7735
              69-        GRID    90              15.     0.      0.
              70-        GRID    97              0.      0.      0.
```

Listing 7-20 Sorted Bulk Data Entries for FSW Airplane in Unsymmetric Maneuvers (Continued)

```
    71-        GRID    98              10.     0.      0.
    72-        GRID    99              20.     0.      0.
    73-        GRID    100             30.     0.      0.
    74-        GRID    110             27.11325+5.     0.
    75-        GRID    111             24.61325+5.     0.
    76-        GRID    112             29.61325+5.     0.
    77-        GRID    120             21.33975+15.    0.
    78-        GRID    121             18.83975+15.    0.
    79-        GRID    122             23.83975+15.    0.
    80-        GRID    210             27.11325-5.     0.
    81-        GRID    211             24.61325-5.     0.
    82-        GRID    212             29.61325-5.     0.
    83-        GRID    220             21.33975-15.    0.
    84-        GRID    221             18.83975-15.    0.
    85-        GRID    222             23.83975-15.    0.
    86-        GRID    310             32.88675+0.     5.
    87-        GRID    311             30.38675+0.     5.
    88-        GRID    312             35.38675+0.     5.
    89-        MAT1    1       1.44+9  5.40+8          0.0
    90-        MAT1    2       1.44+9  5.40+8
    91-        OMIT1   4       110     120     210     220     310
    92-        PAERO1  1000
    93-        PARAM   AUNITS  .031081
    94-        PARAM   GRDPNT  90
    95-        PARAM   WTMASS  .031081
    96-        PBAR    100     1       4.0     .347222 .30     1.0                     +PB1F
    97-        +PB1F   1.0     1.0     1.0     -1.0    -1.0    1.0     -1.0    -1.0    +PB2F
    98-        +PB2F                   0.0
    99-        PBAR    101     2       1.5     0.173611+2.0    0.462963                +PB1W
   100-        +PB1W   0.5     3.0     0.5     -3.0    -0.5    3.0     -0.5    -3.0    +PB2W
   101-        +PB2W                   0.0
   102-        RBAR    111     110     111     123456
   103-        RBAR    112     110     112     123456
   104-        RBAR    121     120     121     123456
   105-        RBAR    122     120     122     123456
   106-        RBAR    211     210     211     123456
   107-        RBAR    212     210     212     123456
   108-        RBAR    221     220     221     123456
   109-        RBAR    222     220     222     123456
   110-        RBAR    311     310     311     123456
   111-        RBAR    312     310     312     123456
   112-        SET1    1000    98      99
   113-        SET1    1100    99      100     111     112     121     122
   114-        SET1    2100    99      100     211     212     221     222
   115-        SET1    3100    99      100     311     312
   116-        SPC1    1       1       90
   117-        SPLINE2 1501    1000    1000    1007    1000    0.      1.      1       +SPRC
   118-        +SPRC   1.      -1.
   119-        SPLINE2 1601    1100    1100    1131    1100    0.      1.      2       +SPRW
   120-        +SPRW   -1.     -1.
   121-        SPLINE2 2501    2000    2000    2007    1000    0.      1.      1       +SPLC
   122-        +SPLC   1.      -1.
   123-        SPLINE2 2601    2100    2100    2131    2100    0.      1.      20      +SPLW
   124-        +SPLW   -1.     -1.
   125-        SPLINE2 3100    3100    3100    3115    3100    0.      1.      300     +SP2FI
   126-        +SP2FI  -1.     -1.
   127-        SUPORT  90      23456
   128-        TRIM    1       0.9     1200.0  PITCH   0.      URDD3   -1.0            +TR1A
   129-        +TR1A   URDD5   0.      AILERON 0.      RUDDER  0.      URDD2   0.      +TR1B
   130-        +TR1B   URDD4   0.      URDD6   0.
   131-        TRIM    2       0.9     1200.0  PITCH   6.0499-4URDD3   -4.8            +TR2A
   132-        +TR2A   URDD5   0.      AILERON .436332 YAW     0.      URDD2   0.      +TR2B
   133-        +TR2B   URDD4   0.      URDD6   0.
   134-        TRIM    3       0.9     1200.0  PITCH   6.0499-4URDD3   -4.8            +TR3A
   135-        +TR3A   URDD5   0.      AILERON .436332 ROLL    0.      YAW     0.      +TR3B
   136-        +TR3B   URDD2   0.      URDD6   0.
   137-        TRIM    4       0.9     1200.0  ANGLEA  .0031512ELEV    .436332         +TR4A
   138-        +TR4A   PITCH   0.      SIDES   0.      ROLL    0.      YAW     0.      +TR4B
   139-        +TR4B   AILERON 0.      RUDDER  .436332
   140-        TRIM    5       0.9     1200.0  PITCH   .2222-3 URDD3   -1.9170         +TR5A
   141-        +TR5A   URDD5   0.      YAW     .5435-3 ROLL    -.3222-4URDD2   0.      +TR5B
   142-        +TR5B   URDD4   0.      URDD6   0.
               ENDDATA

          TOTAL COUNT=        143
```

Listing 7-21 Output for FSW Airplane in Unsymmetric Maneuvers

```
EXAMPLE HA144E: 30 DEG FWD SWEPT WING WITH 3 CONTROLS                                                           PAGE    19
 UNSYMMETRIC FLIGHT CONDITIONS, DOUBLET-LATTICE AERO
 FULL-SPAN MODEL
                      O U T P U T   F R O M   G R I D   P O I N T   W E I G H T   G E N E R A T O R
                                                 REFERENCE POINT =        90
                                                           M O
                  *  1.610000E+04  0.000000E+00  0.000000E+00  0.000000E+00  5.000000E+02  0.000000E+00 *
                  *  0.000000E+00  1.610000E+04  0.000000E+00 -5.000000E+02  0.000000E+00  3.664468E+04 *
                  *  0.000000E+00  0.000000E+00  1.610000E+04  0.000000E+00 -3.664468E+04  0.000000E+00 *
                  *  0.000000E+00 -5.000000E+02  0.000000E+00  5.025000E+05 -2.743320E-12 -8.693375E+03 *
                  *  5.000000E+02  0.000000E+00 -3.664468E+04 -2.743320E-12  1.895271E+06  0.000000E+00 *
                  *  0.000000E+00  3.664468E+04  0.000000E+00 -8.693375E+03  0.000000E+00  2.392771E+06 *
                                                          S
                                       *  1.000000E+00  0.000000E+00  0.000000E+00 *
                                       *  0.000000E+00  1.000000E+00  0.000000E+00 *
                                       *  0.000000E+00  0.000000E+00  1.000000E+00 *
                          DIRECTION
                     MASS AXIS SYSTEM (S)      MASS              X-C.G.        Y-C.G.        Z-C.G.
                             X            1.610000E+04      0.000000E+00  0.000000E+00  3.105590E-02
                             Y            1.610000E+04      2.276067E+00  0.000000E+00  3.105590E-02
                             Z            1.610000E+04      2.276067E+00  0.000000E+00  0.000000E+00
                                                          I(S)
                                       *  5.024845E+05  2.743320E-12  7.555341E+03 *
                                       *  2.743320E-12  1.811849E+06  0.000000E+00 *
                                       *  7.555341E+03  0.000000E+00  2.309365E+06 *
                                                          I(Q)
                                       *  2.309396E+06                             *
                                       *                1.811849E+06               *
                                       *                              5.024528E+05 *
                                                          Q
                                       *  4.181319E-03  0.000000E+00  9.999912E-01 *
                                       *  0.000000E+00  1.000000E+00  0.000000E+00 *
                                       * -9.999912E-01  0.000000E+00  4.181319E-03 *

 FULL-SPAN MODEL                                                                                                 SUBCASE 1
N O N - D I M E N S I O N A L   S T A B I L I T Y   A N D   C O N T R O L   D E R I V A T I V E   C O E F F I C I E N T S

                                    MACH = 9.0000E-01                    Q = 1.2000E+03

           TRANSFORMATION FROM BASIC TO REFERENCE COORDINATES:
         { X }          [ -1.0000   0.0000   0.0000  ]  { X }        { 1.5000E+01 }
         { Y }     =    [  0.0000   1.0000   0.0000  ]  { Y }     +  { 0.0000E+00 }
         { Z }REF       [  0.0000   0.0000  -1.0000  ]  { Z }BAS     { 0.0000E+00 }

TRIM VARIABLE         COEFFICIENT              RIGID                              ELASTIC
                                     UNSPLINED        SPLINED            RESTRAINED      UNRESTRAINED
INTERCEPT               CX          0.000000E+00    0.000000E+00        0.000000E+00    0.000000E+00
                        CY          0.000000E+00    0.000000E+00        0.000000E+00    0.000000E+00
                        CZ          0.000000E+00    0.000000E+00        0.000000E+00    0.000000E+00
                        CMX         0.000000E+00    0.000000E+00        0.000000E+00    0.000000E+00
                        CMY         0.000000E+00    0.000000E+00        0.000000E+00    0.000000E+00
                        CMZ         0.000000E+00    0.000000E+00        0.000000E+00    0.000000E+00

ANGLEA                  CX          0.000000E+00    0.000000E+00        0.000000E+00    0.000000E+00
                        CY         -2.234378E-09   -2.234378E-09        3.806870E-09    8.062219E-09
                        CZ         -5.070976E+00   -5.070976E+00       -6.462928E+00   -7.788311E+00
                        CMX         1.283833E-08    1.283833E-08        1.091487E-08    1.202968E-08
                        CMY        -2.870931E+00   -2.870931E+00       -3.667061E+00   -4.589579E+00
                        CMZ         1.899695E-09    1.899696E-09       -5.304986E-10   -1.447366E-09

PITCH                   CX          0.000000E+00    0.000000E+00        0.000000E+00    0.000000E+00
                        CY         -2.518316E-08   -2.518316E-08       -1.639074E-08   -7.871786E-09
                        CZ         -1.207429E+01   -1.207429E+01       -1.285577E+01   -1.616588E+01
                        CMX         5.162128E-08    5.162128E-08        5.135293E-08    5.086361E-08
                        CMY        -9.953999E+00   -9.953999E+00       -1.027400E+01   -1.254529E+01
                        CMZ         1.785854E-08    1.785855E-08        1.372134E-08    1.210880E-08

URDD3                   CX          0.000000E+00    0.000000E+00        0.000000E+00    0.000000E+00
                        CY          0.000000E+00    0.000000E+00       -9.429442E-12    0.000000E+00
                        CZ          0.000000E+00    0.000000E+00        3.809273E-03    0.000000E+00
                        CMX         0.000000E+00    0.000000E+00       -8.711054E-12    0.000000E+00
                        CMY         0.000000E+00    0.000000E+00        2.737913E-03    0.000000E+00
                        CMZ         0.000000E+00    0.000000E+00        1.318927E-12    0.000000E+00

URDD5                   CX          0.000000E+00    0.000000E+00        0.000000E+00    0.000000E+00
                        CY          0.000000E+00    0.000000E+00       -1.529144E-10    0.000000E+00
                        CZ          0.000000E+00    0.000000E+00        7.602825E-02    0.000000E+00
                        CMX         0.000000E+00    0.000000E+00       -1.348617E-10    0.000000E+00
                        CMY         0.000000E+00    0.000000E+00        4.935852E-02    0.000000E+00
                        CMZ         0.000000E+00    0.000000E+00        3.228951E-11    0.000000E+00
```

Listing 7-21 Output for FSW Airplane in Unsymmetric Maneuvers (Continued)

```
ELEV              CX         0.000000E+00   0.000000E+00     0.000000E+00   0.000000E+00
                  CY        -1.429685E-08  -1.429685E-08    -1.293225E-08  -1.357400E-08
                  CZ        -2.461396E-01  -2.461396E-01    -5.429845E-01  -5.180751E-01
                  CMX        1.660761E-09   1.660761E-09     1.329735E-09   1.130246E-09
                  CMY        5.715299E-01   5.715300E-01     3.860484E-01   3.979848E-01
                  CMZ        3.765754E-09   3.765754E-09     3.320143E-09   3.563355E-09

SIDES             CX         0.000000E+00   0.000000E+00     0.000000E+00   0.000000E+00
                  CY        -7.158447E-01  -7.158447E-01    -6.697496E-01  -7.259906E-01
                  CZ        -2.789167E-08  -2.789167E-08    -2.689029E-08  -3.533381E-08
                  CMX       -3.276105E-02  -3.276105E-02    -2.824561E-02  -2.706761E-02
                  CMY       -3.088518E-08  -2.386878E-08    -2.273260E-08  -2.927150E-08
                  CMZ        2.592296E-01   2.592296E-01     2.425404E-01   2.630059E-01

YAW               CX         0.000000E+00   0.000000E+00     0.000000E+00   0.000000E+00
                  CY         7.233017E-01   7.233017E-01     6.675829E-01   7.284539E-01
                  CZ         2.641076E-08   2.641076E-08     2.099408E-08   2.885544E-08
                  CMX        4.298553E-02   4.298553E-02     3.858262E-02   3.630287E-02
                  CMY        3.223686E-08   2.676262E-08     2.267642E-08   2.890590E-08
                  CMZ       -2.775080E-01  -2.775080E-01    -2.572732E-01  -2.794171E-01

ROLL              CX         0.000000E+00   0.000000E+00     0.000000E+00   0.000000E+00
                  CY         7.965026E-02   7.965026E-02     1.209624E-01   9.466008E-02
                  CZ        -5.020057E-08  -5.020057E-08    -1.362767E-07  -1.260261E-07
                  CMX       -4.184672E-01  -4.184672E-01    -5.070223E-01  -4.448231E-01
                  CMY        3.861513E-08   1.440686E-08    -3.228925E-08  -3.193764E-08
                  CMZ       -2.605253E-02  -2.605253E-02    -4.053827E-02  -3.137653E-02

URDD2             CX         0.000000E+00   0.000000E+00     0.000000E+00   0.000000E+00
                  CY         0.000000E+00   0.000000E+00     7.188179E-04   0.000000E+00
                  CZ         0.000000E+00   0.000000E+00     2.894271E-11   0.000000E+00
                  CMX        0.000000E+00   0.000000E+00     3.018458E-05   0.000000E+00
                  CMY        0.000000E+00   0.000000E+00     2.437238E-11   0.000000E+00
                  CMZ        0.000000E+00   0.000000E+00    -2.601771E-04   0.000000E+00

URDD4             CX         0.000000E+00   0.000000E+00     0.000000E+00   0.000000E+00
                  CY         0.000000E+00   0.000000E+00     2.021708E-03   0.000000E+00
                  CZ         0.000000E+00   0.000000E+00    -1.250726E-09   0.000000E+00
                  CMX        0.000000E+00   0.000000E+00    -3.636955E-03   0.000000E+00
                  CMY        0.000000E+00   0.000000E+00    -5.123050E-10   0.000000E+00
                  CMZ        0.000000E+00   0.000000E+00    -7.117986E-04   0.000000E+00

URDD6             CX         0.000000E+00   0.000000E+00     0.000000E+00   0.000000E+00
                  CY         0.000000E+00   0.000000E+00    -2.213319E-02   0.000000E+00
                  CZ         0.000000E+00   0.000000E+00    -8.478067E-10   0.000000E+00
                  CMX        0.000000E+00   0.000000E+00    -9.981033E-04   0.000000E+00
                  CMY        0.000000E+00   0.000000E+00    -7.639817E-10   0.000000E+00
                  CMZ        0.000000E+00   0.000000E+00     8.080994E-03   0.000000E+00

AILERON           CX         0.000000E+00   0.000000E+00     0.000000E+00   0.000000E+00
                  CY        -1.082397E-01  -1.082397E-01    -1.142208E-01  -1.026434E-01
                  CZ         1.223314E-07   1.223314E-07     1.907469E-07   2.114289E-07
                  CMX        2.747558E-01   2.747558E-01     2.993375E-01   2.624515E-01
                  CMY        6.498798E-08   6.015910E-08     9.951416E-08   1.176604E-07
                  CMZ        3.948339E-02   3.948339E-02     4.149461E-02   3.752521E-02

RUDDER            CX         0.000000E+00   0.000000E+00     0.000000E+00   0.000000E+00
                  CY         3.491402E-01   3.491402E-01     2.996780E-01   3.381170E-01
                  CZ         9.397452E-09   9.397452E-09     3.419316E-09   5.637137E-09
                  CMX        3.745068E-02   3.745068E-02     3.507515E-02   3.228774E-02
                  CMY        1.250881E-08   1.212209E-08     7.706671E-09   9.856436E-09
                  CMZ       -1.706690E-01  -1.706690E-01    -1.525649E-01  -1.665399E-01
```

Listing 7-21 Output for FSW Airplane in Unsymmetric Maneuvers (Continued)

```
                                  INTERMEDIATE MATRIX ... HP

                                           COLUMN      1
   4.021594E-10        1.407690E+00       -5.855442E-09       -7.312004E-02       -2.556327E-11
                                           COLUMN      2
  -9.998472E-09        2.974801E+00       -3.697710E-08       -2.120767E-01       -2.831717E-09
                                           COLUMN      3
  -8.257486E-13        5.589295E-03        5.549625E-12       -1.224622E-04       -3.008684E-15
                                           COLUMN      4
  -2.190958E-11       -7.228872E-04        8.050897E-11       -7.453961E-03       -2.549860E-12
                                           COLUMN      5
  -2.208870E-09        5.403202E-02       -5.456374E-11        6.722745E-03       -3.931490E-10
                                           COLUMN      6
  -1.678953E-01        6.462641E-09        6.878061E-03       -4.676101E-10       -3.704068E-02
                                           COLUMN      7
   1.784256E-01       -5.601964E-09       -1.403152E-02        4.994862E-10        4.077220E-02
                                           COLUMN      8
   3.155028E-02        2.087690E-08        4.272658E-01       -1.371366E-10        6.442385E-03
                                           COLUMN      9
  -5.583723E-03       -6.944514E-12        1.048801E-05        5.006829E-13       -3.089367E-04
                                           COLUMN     10
   3.735903E-04        2.159876E-10        2.427399E-02       -7.083333E-12        5.812574E-05
                                           COLUMN     11
   1.906394E-02        2.094061E-10       -2.522435E-05       -1.604130E-11        1.645562E-02
                                           COLUMN     12
  -3.053800E-02       -4.163063E-08       -2.377971E-01        1.762600E-09       -6.602197E-03
                                           COLUMN     13
   1.061561E-01       -1.208490E-09       -1.858679E-02        1.890525E-10        2.767085E-02
                  A E R O S T A T I C   D A T A   R E C O V E R Y   O U T P U T   T A B L E
                                       AEROELASTIC TRIM VARIABLES
                                      TRIM VARIABLE    VALUE OF UX

                                         ANGLEA        3.151205E-03
                                         PITCH         0.000000E+00
                                         URDD3        -1.000000E+00
                                         URDD5         0.000000E+00
                                         ELEV          1.724982E-02
                                         SIDES        -1.457720E-09
                                         YAW          -1.182399E-09
                                         ROLL          1.214894E-10
                                         URDD2         0.000000E+00
                                         URDD4         0.000000E+00
                                         URDD6         0.000000E+00
                                         AILERON       0.000000E+00
                                         RUDDER        0.000000E+00

                  A E R O S T A T I C   D A T A   R E C O V E R Y   O U T P U T   T A B L E
                             MACH = 9.000000E-01                  Q = 1.200000E+03

                                                                            AERODYNAMIC FORCES
 AERODYNAMIC              AERODYNAMIC PRES.    AERODYNAMIC
        GRID   LABEL       COEFFICIENTS         PRESSURES         EXTERNAL ID  LABEL  NORMAL FORCES(T3)  MOMENTS(R2)
             1      LS      1.480992E-01        1.777191E+02          1000     LS     1.110744E+03       6.942151E+02
             2      LS      2.723155E-02        3.267786E+01          1001     LS     2.042366E+02       1.276479E+02
             3      LS      1.154897E-02        1.385876E+01          1002     LS     8.661728E+01       5.413580E+01
             4      LS      9.633810E-03        1.156057E+01          1003     LS     7.225358E+01       4.515849E+01
             5      LS      1.172538E-01        1.407045E+02          1004     LS     8.794033E+02       5.496271E+02
             6      LS      1.959021E-02        2.350826E+01          1005     LS     1.469266E+02       9.182912E+01
             7      LS      8.839857E-03        1.060783E+01          1006     LS     6.629893E+01       4.143683E+01
             8      LS      8.520475E-03        1.022457E+01          1007     LS     6.390356E+01       3.993972E+01
             9      LS     -3.474722E-02       -4.169667E+01          1100     LS    -2.606042E+02      -1.628776E+02
            10      LS     -3.303323E-03       -3.963988E+00          1101     LS    -2.477492E+01      -1.548433E+01
            11      LS     -6.613627E-04       -7.936352E-01          1102     LS    -4.960220E+00      -3.100138E+00
            12      LS     -1.289034E-04       -1.546841E-01          1103     LS    -9.667754E-01      -6.042346E-01
            13      LS      7.057209E-03        8.468651E+00          1104     LS     5.292907E+01       3.308067E+01
            14      LS     -2.407379E-03       -2.888855E+00          1105     LS    -1.805535E+01      -1.128459E+01
            15      LS     -2.951239E-04       -3.541487E-01          1106     LS    -2.213429E+00      -1.383394E+00
            16      LS     -1.041256E-03       -1.249507E+00          1107     LS    -7.809415E+00      -4.880884E+00
            17      LS      1.412354E-01        1.694825E+02          1108     LS     1.059265E+03       6.620409E+02
            18      LS      1.587099E-02        1.904519E+01          1109     LS     1.190325E+02       7.439529E+01
            19      LS      2.484603E-03        2.981524E+00          1110     LS     1.863452E+01       1.164658E+01
            20      LS     -2.250555E-03       -2.700666E+00          1111     LS    -1.687916E+01      -1.054948E+01
            21      LS      1.082991E-01        1.299589E+02          1112     LS     8.122433E+02       5.076521E+02
            22      LS      3.481510E-02        4.177812E+01          1113     LS     2.611133E+02       1.631958E+02
            23      LS      9.695046E-03        1.163406E+01          1114     LS     7.271284E+01       4.544553E+01
            24      LS      2.207176E-03        2.648612E+00          1115     LS     1.655382E+01       1.034614E+01
            25      LS      8.606955E-02        1.032835E+02          1116     LS     6.455216E+02       4.034510E+02
```

Listing 7-21 Output for FSW Airplane in Unsymmetric Maneuvers (Continued)

```
        26     LS      3.688312E-02       4.425974E+01              1117   LS      2.766234E+02       1.728896E+02
        27     LS      1.592299E-02       1.910759E+01              1118   LS      1.194224E+02       7.463902E+01
        28     LS      5.199344E-03       6.239213E+00              1119   LS      3.899508E+01       2.437193E+01
        29     LS      6.924295E-02       8.309155E+01              1120   LS      5.193221E+02       3.245764E+02
        30     LS      3.236257E-02       3.883508E+01              1121   LS      2.427193E+02       1.516995E+02
        31     LS      1.798351E-02       2.158021E+01              1122   LS      1.348763E+02       8.429770E+01
        32     LS      7.599713E-03       9.119656E+00              1123   LS      5.699784E+01       3.562365E+01
        33     LS      5.357746E-02       6.429295E+01              1124   LS      4.018310E+02       2.511443E+02
        34     LS      2.556036E-02       3.067244E+01              1125   LS      1.917027E+02       1.198142E+02
        35     LS      1.627770E-02       1.953324E+01              1126   LS      1.220827E+02       7.630171E+01
        36     LS      8.524692E-03       1.022963E+01              1127   LS      6.393519E+01       3.995949E+01
        37     LS      3.548426E-02       4.258111E+01              1128   LS      2.661319E+02       1.663325E+02
        38     LS      1.658309E-02       1.989970E+01              1129   LS      1.243731E+02       7.773322E+01
        39     LS      1.138929E-02       1.366715E+01              1130   LS      8.541969E+01       5.338730E+01
        40     LS      7.125350E-03       8.550420E+00              1131   LS      5.344012E+01       3.340008E+01
        41     LS      1.172538E-01       1.407045E+02              2000   LS      8.794033E+02       5.496271E+02
        42     LS      1.959022E-02       2.350826E+01              2001   LS      1.469266E+02       9.182914E+01
        43     LS      8.839858E-03       1.060783E+01              2002   LS      6.629893E+01       4.143683E+01
        44     LS      8.520480E-03       1.022458E+01              2003   LS      6.390360E+01       3.993975E+01
        45     LS      1.480992E-01       1.777191E+02              2004   LS      1.110744E+03       6.942150E+02
        46     LS      2.723155E-02       3.267786E+01              2005   LS      2.042366E+02       1.276479E+02
        47     LS      1.154897E-02       1.385876E+01              2006   LS      8.661728E+01       5.413580E+01
        48     LS      9.633814E-03       1.156058E+01              2007   LS      7.225360E+01       4.515850E+01
        49     LS      3.548426E-02       4.258112E+01              2100   LS      2.661320E+02       1.663325E+02
        50     LS      1.658307E-02       1.989969E+01              2101   LS      1.243731E+02       7.773318E+01
        51     LS      1.138929E-02       1.366715E+01              2102   LS      8.541971E+01       5.338732E+01
        52     LS      7.125352E-03       8.550422E+00              2103   LS      5.344014E+01       3.340009E+01
        53     LS      5.357747E-02       6.429296E+01              2104   LS      4.018310E+02       2.511444E+02
        54     LS      2.556036E-02       3.067244E+01              2105   LS      1.917027E+02       1.198142E+02
        55     LS      1.627768E-02       1.953322E+01              2106   LS      1.220826E+02       7.630165E+01
        56     LS      8.524698E-03       1.022964E+01              2107   LS      6.393523E+01       3.995952E+01
        57     LS      6.924295E-02       8.309154E+01              2108   LS      5.193221E+02       3.245763E+02
        58     LS      3.236258E-02       3.883509E+01              2109   LS      2.427194E+02       1.516996E+02
        59     LS      1.798349E-02       2.158019E+01              2110   LS      1.348762E+02       8.429765E+01
        60     LS      7.599720E-03       9.119664E+00              2111   LS      5.699791E+01       3.562369E+01
        61     LS      8.606955E-02       1.032835E+02              2112   LS      6.455215E+02       4.034510E+02
        62     LS      3.688312E-02       4.425974E+01              2113   LS      2.766234E+02       1.728896E+02
        63     LS      1.592300E-02       1.910760E+01              2114   LS      1.194225E+02       7.463905E+01
        64     LS      5.199342E-03       6.239211E+00              2115   LS      3.899507E+01       2.437192E+01
        65     LS      1.082991E-01       1.299590E+02              2116   LS      8.122435E+02       5.076522E+02
        66     LS      3.481508E-02       4.177809E+01              2117   LS      2.611131E+02       1.631957E+02
        67     LS      9.695059E-03       1.163407E+01              2118   LS      7.271294E+01       4.544559E+01
        68     LS      2.207176E-03       2.648611E+00              2119   LS      1.655382E+01       1.034614E+01
        69     LS      1.412354E-01       1.694825E+02              2120   LS      1.059266E+03       6.620410E+02
        70     LS      1.587098E-02       1.904517E+01              2121   LS      1.190323E+02       7.439520E+01
        71     LS      2.484598E-03       2.981517E+00              2122   LS      1.863449E+01       1.164656E+01
        72     LS     -2.250552E-03      -2.700662E+00              2123   LS     -1.687914E+01      -1.054947E+01
        73     LS      7.057216E-03       8.468659E+00              2124   LS      5.292912E+01       3.308070E+01
        74     LS     -2.407386E-03      -2.888864E+00              2125   LS     -1.805540E+01      -1.128462E+01
        75     LS     -2.951450E-04      -3.541740E-01              2126   LS     -2.213588E+00      -1.383493E+00
        76     LS     -1.041241E-03      -1.249489E+00              2127   LS     -7.809305E+00      -4.880816E+00
        77     LS     -3.474717E-02      -4.169661E+01              2128   LS     -2.606038E+02      -1.628774E+02
        78     LS     -3.303373E-03      -3.964047E+00              2129   LS     -2.477530E+01      -1.548456E+01
        79     LS     -6.613678E-04      -7.936413E-01              2130   LS     -4.960258E+00      -3.100161E+00
        80     LS     -1.289032E-04      -1.546838E-01              2131   LS     -9.667740E-01      -6.042337E-01
        81     LS      1.526758E-09       1.832109E-06              3100   LS      1.145068E-05       7.156677E-06
        82     LS     -1.036260E-09      -1.243512E-06              3101   LS     -7.771948E-06      -4.857468E-06
        83     LS     -1.645607E-11      -1.974728E-08              3102   LS     -1.234205E-07      -7.713783E-08
        84     LS     -5.575136E-10      -6.690163E-07              3103   LS     -4.181352E-06      -2.613346E-06
        85     LS      3.053273E-09       3.663927E-06              3104   LS      2.289954E-05       1.431222E-05
        86     LS     -2.462315E-09      -2.954778E-06              3105   LS     -1.846737E-05      -1.154210E-05
        87     LS     -2.511690E-10      -3.014028E-07              3106   LS     -1.883768E-06      -1.177355E-06
        88     LS     -8.563940E-10      -1.027673E-06              3107   LS     -6.422955E-06      -4.014347E-06
        89     LS      1.070075E-09       1.284090E-06              3108   LS      8.025565E-06       5.015978E-06
        90     LS      3.735966E-10       4.483159E-07              3109   LS      2.801974E-06       1.751234E-06
        91     LS     -5.124166E-10      -6.148999E-07              3110   LS     -3.843124E-06      -2.401953E-06
        92     LS     -4.349331E-10      -5.219197E-07              3111   LS     -3.261998E-06      -2.038749E-06
        93     LS     -1.056676E-08      -1.268011E-05              3112   LS     -7.925069E-05      -4.953168E-05
        94     LS      1.122110E-08       1.346532E-05              3113   LS      8.415823E-05       5.259889E-05
        95     LS     -1.116792E-09      -1.340150E-06              3114   LS     -8.375938E-06      -5.234961E-06
        96     LS      5.662081E-10       6.794498E-07              3115   LS      4.246561E-06       2.654101E-06
*** LABEL NOTATIONS:  LS = LIFTING SURFACE,  ZIB = Z INTERFERENCE BODY ELEMENT,  ZSB = Z SLENDER BODY ELEMENT,
                                             YIB = Y INTERFERENCE BODY ELEMENT,  YSB = Y SLENDER BODY ELEMENT.
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Listing 7-21 Output for FSW Airplane in Unsymmetric Maneuvers (Continued)

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 FULL-SPAN MODEL                                                                                     SUBCASE 2

                          A E R O S T A T I C   D A T A   R E C O V E R Y   O U T P U T   T A B L E
                                                 AEROELASTIC TRIM VARIABLES
                                                TRIM VARIABLE    VALUE OF UX

                                                   ANGLEA        1.370419E-02
                                                   PITCH         6.049900E-04
                                                   URDD3        -4.800000E+00
                                                   URDD5         0.000000E+00
                                                   ELEV          8.539610E-02
                                                   SIDES        -1.823546E-02
                                                   YAW           0.000000E+00
                                                   ROLL          2.600431E-01
                                                   URDD2         0.000000E+00
                                                   URDD4         0.000000E+00
                                                   URDD6        -2.168404E-19
                                                   AILERON       4.363320E-01
                                                   RUDDER        2.058725E-02

                          A E R O S T A T I C   D A T A   R E C O V E R Y   O U T P U T   T A B L E
                                    MACH = 9.000000E-01                Q = 1.200000E+03

                                                                               AERODYNAMIC FORCES
    AERODYNAMIC           AERODYNAMIC PRES.    AERODYNAMIC
           GRID   LABEL     COEFFICIENTS        PRESSURES          EXTERNAL ID  LABEL  NORMAL FORCES(T3)  MOMENTS(R2)
              1     LS      7.864448E-01       9.437338E+02              1000    LS      5.898336E+03      3.686460E+03
              2     LS      1.396064E-01       1.675277E+02              1001    LS      1.047048E+03      6.544051E+02
              3     LS      6.360418E-02       7.632501E+01              1002    LS      4.770313E+02      2.981446E+02
              4     LS      5.981490E-02       7.177788E+01              1003    LS      4.486117E+02      2.803823E+02
              5     LS      7.315380E-01       8.778456E+02              1004    LS      5.486535E+03      3.429084E+03
              6     LS      1.086405E-01       1.303686E+02              1005    LS      8.148035E+02      5.092522E+02
              7     LS      5.830283E-02       6.996339E+01              1006    LS      4.372712E+02      2.732945E+02
              8     LS      7.348040E-02       8.817648E+01              1007    LS      5.511030E+02      3.444394E+02
              9     LS     -4.793925E-02      -5.752710E+01              1100    LS     -3.595444E+02     -2.247152E+02
             10     LS      1.212338E-02       1.454806E+01              1101    LS      9.092536E+01      5.682835E+01
             11     LS     -2.603003E-02      -3.123603E+01              1102    LS     -1.952252E+02     -1.220158E+02
             12     LS     -3.782949E-03      -4.539539E+00              1103    LS     -2.837212E+01     -1.773257E+01
             13     LS      3.487090E-01       4.184508E+02              1104    LS      2.615318E+03      1.634574E+03
             14     LS     -4.106984E-02      -4.928381E+01              1105    LS     -3.080238E+02     -1.925149E+02
             15     LS     -6.558547E-02      -7.870257E+01              1106    LS     -4.918911E+02     -3.074320E+02
             16     LS     -4.328452E-02      -5.194143E+01              1107    LS     -3.246339E+02     -2.028962E+02
             17     LS      1.517685E+00       1.821222E+03              1108    LS      1.138264E+04      7.114149E+03
             18     LS      7.238707E-02       8.686449E+01              1109    LS      5.429031E+02      3.393144E+02
             19     LS     -1.522643E-01      -1.827172E+02              1110    LS     -1.141982E+03     -7.137390E+02
             20     LS     -1.218619E-01      -1.462342E+02              1111    LS     -9.139639E+02     -5.712275E+02
             21     LS      1.587969E+00       1.905563E+03              1112    LS      1.190977E+04      7.443606E+03
             22     LS      2.385288E-01       2.862346E+02              1113    LS      1.788966E+03      1.118104E+03
             23     LS     -2.716918E-01      -3.260302E+02              1114    LS     -2.037689E+03     -1.273556E+03
             24     LS     -3.019391E-01      -3.623269E+02              1115    LS     -2.264543E+03     -1.415339E+03
             25     LS      1.673347E+00       2.008017E+03              1116    LS      1.255010E+04      7.843815E+03
             26     LS      3.382304E-01       4.058765E+02              1117    LS      2.536728E+03      1.585455E+03
             27     LS     -3.085978E-01      -3.703174E+02              1118    LS     -2.314483E+03     -1.446552E+03
             28     LS     -1.427823E+00      -1.713388E+03              1119    LS     -1.070867E+04     -6.692922E+03
             29     LS      1.705563E+00       2.046675E+03              1120    LS      1.279172E+04      7.994825E+03
             30     LS      4.176543E-01       5.011851E+02              1121    LS      3.132407E+03      1.957754E+03
             31     LS     -2.567720E-01      -3.081264E+02              1122    LS     -1.925790E+03     -1.203619E+03
             32     LS     -1.599504E+00      -1.919405E+03              1123    LS     -1.199628E+04     -7.497675E+03
             33     LS      1.602263E+00       1.922716E+03              1124    LS      1.201698E+04      7.510610E+03
             34     LS      4.607435E-01       5.528923E+02              1125    LS      3.455577E+03      2.159736E+03
             35     LS     -1.318212E-01      -1.581854E+02              1126    LS     -9.886589E+02     -6.179119E+02
             36     LS     -1.564726E+00      -1.877671E+03              1127    LS     -1.173545E+04     -7.334654E+03
             37     LS      1.246066E+00       1.495279E+03              1128    LS      9.345496E+03      5.840936E+03
             38     LS      3.864193E-01       4.637032E+02              1129    LS      2.898145E+03      1.811341E+03
             39     LS      4.524189E-02       5.429027E+01              1130    LS      3.393142E+02      2.120714E+02
             40     LS     -1.317840E+00      -1.581409E+03              1131    LS     -9.883804E+03     -6.177377E+03
             41     LS      4.035736E-01       4.842884E+02              2000    LS      3.026802E+03      1.891751E+03
             42     LS      8.393354E-02       1.007202E+02              2001    LS      6.295015E+02      3.934384E+02
             43     LS      3.022441E-02       3.626929E+01              2002    LS      2.266831E+02      1.416769E+02
             44     LS      1.113158E-02       1.335789E+01              2003    LS      8.348683E+01      5.217927E+01
             45     LS      6.473656E-01       7.768387E+02              2004    LS      4.855242E+03      3.034526E+03
             46     LS      1.277147E-01       1.532577E+02              2005    LS      9.578604E+02      5.986628E+02
             47     LS      5.201303E-02       6.241564E+01              2006    LS      3.900977E+02      2.438111E+02
             48     LS      3.632584E-02       4.359101E+01              2007    LS      2.724438E+02      1.702774E+02
             49     LS     -9.168379E-01      -1.100205E+03              2100    LS     -6.876284E+03     -4.297677E+03
             50     LS     -2.280832E-01      -2.736999E+02              2101    LS     -1.710624E+03     -1.069140E+03
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Listing 7-21 Output for FSW Airplane in Unsymmetric Maneuvers (Continued)

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      51     LS      6.587906E-02       7.905488E+01              2102    LS     4.940930E+02       3.088081E+02
      52     LS      1.388865E+00       1.666639E+03              2103    LS     1.041649E+04       6.510307E+03
      53     LS     -1.101580E+00      -1.321896E+03              2104    LS    -8.261851E+03      -5.163657E+03
      54     LS     -2.160054E-01      -2.592064E+02              2105    LS    -1.620040E+03      -1.012525E+03
      55     LS      2.907227E-01       3.488673E+02              2106    LS     2.180421E+03       1.362763E+03
      56     LS      1.649767E+00       1.979721E+03              2107    LS     1.237325E+04       7.733284E+03
      57     LS     -1.054028E+00      -1.264833E+03              2108    LS    -7.905208E+03      -4.940755E+03
      58     LS     -1.068757E-01      -1.282508E+02              2109    LS    -8.015675E+02      -5.009798E+02
      59     LS      4.325479E-01       5.190575E+02              2110    LS     3.244110E+03       2.027569E+03
      60     LS      1.675814E+00       2.010976E+03              2111    LS     1.256860E+04       7.855376E+03
      61     LS     -8.580897E-01      -1.029708E+03              2112    LS    -6.435673E+03      -4.022296E+03
      62     LS      1.679588E-02       2.015505E+01              2113    LS     1.259691E+02       7.873070E+01
      63     LS      4.646642E-01       5.575970E+02              2114    LS     3.484981E+03       2.178113E+03
      64     LS      1.481088E+00       1.777306E+03              2115    LS     1.110816E+04       6.942601E+03
      65     LS     -5.555010E-01      -6.666012E+02              2116    LS    -4.166257E+03      -2.603911E+03
      66     LS      9.684183E-02       1.162102E+02              2117    LS     7.263138E+02       4.539461E+02
      67     LS      3.676826E-01       4.412191E+02              2118    LS     2.757620E+03       1.723512E+03
      68     LS      3.265942E-01       3.919131E+02              2119    LS     2.449457E+03       1.530911E+03
      69     LS     -1.633413E-01      -1.960096E+02              2120    LS    -1.225060E+03      -7.656625E+02
      70     LS      7.936113E-02       9.523335E+01              2121    LS     5.952085E+02       3.720053E+02
      71     LS      1.791099E-01       2.149318E+02              2122    LS     1.343324E+03       8.395778E+02
      72     LS      1.042501E-01       1.251001E+02              2123    LS     7.818759E+02       4.886725E+02
      73     LS     -2.986870E-01      -3.584244E+02              2124    LS    -2.240152E+03      -1.400095E+03
      74     LS      1.669648E-02       2.003577E+01              2125    LS     1.252236E+02       7.826473E+01
      75     LS      6.635843E-02       7.963012E+01              2126    LS     4.976884E+02       3.110553E+02
      76     LS      3.727235E-02       4.472682E+01              2127    LS     2.795426E+02       1.747141E+02
      77     LS     -3.086562E-01      -3.703875E+02              2128    LS    -2.314922E+03      -1.446826E+03
      78     LS     -4.308398E-02      -5.170077E+01              2129    LS    -3.231298E+02      -2.019561E+02
      79     LS      2.404013E-02       2.884816E+01              2130    LS     1.803010E+02       1.126881E+02
      80     LS      6.305821E-03       7.566985E+00              2131    LS     4.729366E+01       2.955853E+01
      81     LS     -2.999334E-01      -3.599201E+02              3100    LS    -2.249500E+03      -1.405938E+03
      82     LS     -2.692820E-02      -3.231384E+01              3101    LS    -2.019615E+02      -1.262259E+02
      83     LS      9.641200E-03       1.156944E+01              3102    LS     7.230900E+01       4.519312E+01
      84     LS      6.186832E-02       7.424199E+01              3103    LS     4.640125E+02       2.900078E+02
      85     LS     -1.522581E-01      -1.827097E+02              3104    LS    -1.141936E+03      -7.137099E+02
      86     LS     -6.095775E-02      -7.314930E+01              3105    LS    -4.571831E+02      -2.857395E+02
      87     LS      1.336691E-03       1.604029E+00              3106    LS     1.002518E+01       6.265737E+00
      88     LS      7.109066E-02       8.530879E+01              3107    LS     5.331800E+02       3.332375E+02
      89     LS      8.106790E-02       9.728148E+01              3108    LS     6.080092E+02       3.800058E+02
      90     LS     -5.076220E-02      -6.091463E+01              3109    LS    -3.807165E+02      -2.379478E+02
      91     LS     -1.349962E-02      -1.619954E+01              3110    LS    -1.012471E+02      -6.327945E+01
      92     LS      6.774797E-02       8.129756E+01              3111    LS     5.081098E+02       3.175686E+02
      93     LS      2.938147E-01       3.525776E+02              3112    LS     2.203610E+03       1.377256E+03
      94     LS     -8.344214E-03      -1.001306E+01              3113    LS    -6.258160E+01      -3.911350E+01
      95     LS     -2.760044E-02      -3.312052E+01              3114    LS    -2.070033E+02      -1.293770E+02
      96     LS      5.371650E-02       6.445979E+01              3115    LS     4.028737E+02       2.517961E+02
*** LABEL NOTATIONS:  LS = LIFTING SURFACE,  ZIB = Z INTERFERENCE BODY ELEMENT,  ZSB = Z SLENDER BODY ELEMENT,
                                         YIB = Y INTERFERENCE BODY ELEMENT,  YSB = Y SLENDER BODY ELEMENT.

FULL-SPAN MODEL                                                                                    SUBCASE 3
                          A E R O S T A T I C   D A T A   R E C O V E R Y   O U T P U T   T A B L E
                                               AEROELASTIC TRIM VARIABLES
                                              TRIM VARIABLE    VALUE OF UX

                                                 ANGLEA        1.370419E-02
                                                 PITCH         6.049900E-04
                                                 URDD3        -4.800000E+00
                                                 URDD5         0.000000E+00
                                                 ELEV          8.539611E-02
                                                 SIDES        -6.297442E-02
                                                 YAW           9.658545E-19
                                                 ROLL          0.000000E+00
                                                 URDD2         0.000000E+00
                                                 URDD4         4.454218E+00
                                                 URDD6        -2.168404E-19
                                                 AILERON       4.363320E-01
                                                 RUDDER        1.099768E-02
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Main Index

Listing 7-21 Output for FSW Airplane in Unsymmetric Maneuvers (Continued)

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                     A E R O S T A T I C   D A T A   R E C O V E R Y   O U T P U T   T A B L E
                                 MACH = 9.000000E-01                     Q = 1.200000E+03
                                                                                  AERODYNAMIC FORCES
   AERODYNAMIC           AERODYNAMIC PRES.    AERODYNAMIC
          GRID   LABEL     COEFFICIENTS        PRESSURES            EXTERNAL ID  LABEL  NORMAL FORCES(T3)  MOMENTS(R2)
             1     LS      7.164526E-01      8.597431E+02                  1000    LS      5.373395E+03      3.358371E+03
             2     LS      1.330722E-01      1.596866E+02                  1001    LS      9.980414E+02      6.237759E+02
             3     LS      5.625242E-02      6.750291E+01                  1002    LS      4.218932E+02      2.636832E+02
             4     LS      4.402409E-02      5.282891E+01                  1003    LS      3.301807E+02      2.063629E+02
             5     LS      5.665109E-01      6.798130E+02                  1004    LS      4.248832E+03      2.655520E+03
             6     LS      9.494174E-02      1.139301E+02                  1005    LS      7.120630E+02      4.450394E+02
             7     LS      4.063968E-02      4.876761E+01                  1006    LS      3.047976E+02      1.904985E+02
             8     LS      3.221849E-02      3.866218E+01                  1007    LS      2.416386E+02      1.510242E+02
             9     LS     -2.400071E-01     -2.880085E+02                  1100    LS     -1.800053E+03     -1.125033E+03
            10     LS     -5.004971E-02     -6.005965E+01                  1101    LS     -3.753728E+02     -2.346080E+02
            11     LS     -3.032419E-02     -3.638903E+01                  1102    LS     -2.274315E+02     -1.421447E+02
            12     LS     -3.890117E-03     -4.668140E+00                  1103    LS     -2.917587E+01     -1.823492E+01
            13     LS     -1.212328E-01     -1.454794E+02                  1104    LS     -9.092462E+02     -5.682789E+02
            14     LS     -1.437190E-01     -1.724628E+02                  1105    LS     -1.077892E+03     -6.736827E+02
            15     LS     -9.253818E-02     -1.110458E+02                  1106    LS     -6.940364E+02     -4.337728E+02
            16     LS     -4.014689E-02     -4.817627E+01                  1107    LS     -3.011017E+02     -1.881885E+02
            17     LS      4.887081E-01      5.864497E+02                  1108    LS      3.665311E+03      2.290819E+03
            18     LS     -1.470592E-01     -1.764710E+02                  1109    LS     -1.102944E+03     -6.893400E+02
            19     LS     -2.159077E-01     -2.590893E+02                  1110    LS     -1.619308E+03     -1.012068E+03
            20     LS     -1.244790E-01     -1.493748E+02                  1111    LS     -9.335923E+02     -5.834952E+02
            21     LS      3.513409E-01      4.216090E+02                  1112    LS      2.635056E+03      1.646910E+03
            22     LS     -1.128529E-01     -1.354234E+02                  1113    LS     -8.463965E+02     -5.289978E+02
            23     LS     -3.923257E-01     -4.707908E+02                  1114    LS     -2.942443E+03     -1.839027E+03
            24     LS     -3.349355E-01     -4.019226E+02                  1115    LS     -2.512016E+03     -1.570010E+03
            25     LS      2.979548E-01      3.575457E+02                  1116    LS      2.234661E+03      1.396663E+03
            26     LS     -1.002865E-01     -1.203438E+02                  1117    LS     -7.521486E+02     -4.700929E+02
            27     LS     -4.860806E-01     -5.832968E+02                  1118    LS     -3.645605E+03     -2.278503E+03
            28     LS     -1.488213E+00     -1.785856E+03                  1119    LS     -1.116160E+04     -6.975999E+03
            29     LS      2.788988E-01      3.346785E+02                  1120    LS      2.091741E+03      1.307338E+03
            30     LS     -6.212339E-02     -7.454807E+01                  1121    LS     -4.659254E+02     -2.912034E+02
            31     LS     -4.741541E-01     -5.689850E+02                  1122    LS     -3.556156E+03     -2.222598E+03
            32     LS     -1.685115E+00     -2.022138E+03                  1123    LS     -1.263836E+04     -7.898977E+03
            33     LS      2.503476E-01      3.004172E+02                  1124    LS      1.877607E+03      1.173505E+03
            34     LS     -2.328361E-03     -2.794033E+00                  1125    LS     -1.746271E+01     -1.091419E+01
            35     LS     -3.588144E-01     -4.305772E+02                  1126    LS     -2.691108E+03     -1.681942E+03
            36     LS     -1.666845E+00     -2.000214E+03                  1127    LS     -1.250134E+04     -7.813336E+03
            37     LS      1.853577E-01      2.224293E+02                  1128    LS      1.390183E+03      8.688643E+02
            38     LS      3.228679E-02      3.874414E+01                  1129    LS      2.421509E+02      1.513443E+02
            39     LS     -1.375535E-01     -1.650642E+02                  1130    LS     -1.031651E+03     -6.447819E+02
            40     LS     -1.411519E+00     -1.693823E+03                  1131    LS     -1.058639E+04     -6.616495E+03
            41     LS      5.686010E-01      6.823212E+02                  2000    LS      4.264507E+03      2.665317E+03
            42     LS      9.763229E-02      1.171587E+02                  2001    LS      7.322422E+02      4.576514E+02
            43     LS      4.788753E-02      5.746504E+01                  2002    LS      3.591565E+02      2.244728E+02
            44     LS      5.239346E-02      6.287215E+01                  2003    LS      3.929509E+02      2.455943E+02
            45     LS      7.173581E-01      8.608297E+02                  2004    LS      5.380186E+03      3.362616E+03
            46     LS      1.342490E-01      1.610988E+02                  2005    LS      1.006867E+03      6.292921E+02
            47     LS      5.936474E-02      7.123769E+01                  2006    LS      4.452356E+02      2.782722E+02
            48     LS      5.211661E-02      6.253994E+01                  2007    LS      3.908746E+02      2.442966E+02
            49     LS      1.438708E-01      1.726450E+02                  2100    LS      1.079031E+03      6.743944E+02
            50     LS      1.260490E-01      1.512588E+02                  2101    LS      9.453678E+02      5.908550E+02
            51     LS      2.486745E-01      2.984094E+02                  2102    LS      1.865059E+03      1.165662E+03
            52     LS      1.482544E+00      1.779053E+03                  2103    LS      1.111908E+04      6.949425E+03
            53     LS      2.503359E-01      3.004030E+02                  2104    LS      1.877519E+03      1.173449E+03
            54     LS      2.470665E-01      2.964799E+02                  2105    LS      1.852999E+03      1.158125E+03
            55     LS      5.177157E-01      6.212589E+02                  2106    LS      3.882868E+03      2.426793E+03
            56     LS      1.751886E+00      2.102263E+03                  2107    LS      1.313915E+04      8.211967E+03
            57     LS      3.726362E-01      4.471634E+02                  2108    LS      2.794771E+03      1.746732E+03
            58     LS      3.729022E-01      4.474826E+02                  2109    LS      2.796766E+03      1.747979E+03
            59     LS      6.499299E-01      7.799159E+02                  2110    LS      4.874475E+03      3.046547E+03
            60     LS      1.761425E+00      2.113710E+03                  2111    LS      1.321069E+04      8.256679E+03
            61     LS      5.173029E-01      6.207635E+02                  2112    LS      3.879772E+03      2.424858E+03
            62     LS      4.553127E-01      5.463752E+02                  2113    LS      3.414845E+03      2.134279E+03
            63     LS      6.421471E-01      7.705765E+02                  2114    LS      4.816103E+03      3.010064E+03
            64     LS      1.541478E+00      1.849773E+03                  2115    LS      1.156108E+04      7.225677E+03
            65     LS      6.811275E-01      8.173531E+02                  2116    LS      5.108457E+03      3.192786E+03
            66     LS      4.482233E-01      5.378679E+02                  2117    LS      3.361674E+03      2.101046E+03
            67     LS      4.883165E-01      5.859798E+02                  2118    LS      3.662374E+03      2.288984E+03
            68     LS      3.595906E-01      4.315088E+02                  2119    LS      2.696930E+03      1.685582E+03
            69     LS      8.656359E-01      1.038763E+03                  2120    LS      6.492269E+03      4.057668E+03
            70     LS      2.988071E-01      3.585685E+02                  2121    LS      2.241053E+03      1.400658E+03
            71     LS      2.427534E-01      2.913040E+02                  2122    LS      1.820651E+03      1.137907E+03
            72     LS      1.068672E-01      1.282406E+02                  2123    LS      8.015040E+02      5.009401E+02
            73     LS      1.712547E-01      2.055057E+02                  2124    LS      1.284411E+03      8.027566E+02
            74     LS      1.193454E-01      1.432145E+02                  2125    LS      8.950905E+02      5.594316E+02
            75     LS      9.331115E-02      1.119734E+02                  2126    LS      6.998337E+02      4.373961E+02
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Listing 7-21 Output for FSW Airplane in Unsymmetric Maneuvers (Continued)

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              76     LS      3.413485E-02      4.096181E+01              2127    LS      2.560114E+02      1.600071E+02
              77     LS     -1.165893E-01     -1.399072E+02              2128    LS     -8.744197E+02     -5.465123E+02
              78     LS      1.908966E-02      2.290759E+01              2129    LS      1.431724E+02      8.948277E+01
              79     LS      2.833431E-02      3.400117E+01              2130    LS      2.125073E+02      1.328170E+02
              80     LS      6.413082E-03      7.695698E+00              2131    LS      4.809811E+01      3.006132E+01
              81     LS      7.503304E-02      9.003964E+01              3100    LS      5.627477E+02      3.517173E+02
              82     LS      2.032789E-03      2.439347E+00              3101    LS      1.524592E+01      9.528701E+00
              83     LS      7.339601E-03      8.807521E+00              3102    LS      5.504700E+01      3.440438E+01
              84     LS      3.333901E-02      4.000681E+01              3103    LS      2.500426E+02      1.562766E+02
              85     LS      5.730936E-02      6.877123E+01              3104    LS      4.298202E+02      2.686376E+02
              86     LS      9.735225E-04      1.168227E+00              3105    LS      7.301420E+00      4.563387E+00
              87     LS      6.672278E-03      8.006733E+00              3106    LS      5.004208E+01      3.127630E+01
              88     LS      3.910184E-02      4.692221E+01              3107    LS      2.932639E+02      1.832899E+02
              89     LS      4.101618E-02      4.921942E+01              3108    LS      3.076213E+02      1.922633E+02
              90     LS     -1.635940E-02     -1.963128E+01              3109    LS     -1.226955E+02     -7.668471E+01
              91     LS     -1.008363E-03     -1.210036E+00              3110    LS     -7.562724E+00     -4.726703E+00
              92     LS      3.825928E-02      4.591113E+01              3111    LS      2.869446E+02      1.793404E+02
              93     LS      4.080638E-02      4.896766E+01              3112    LS      3.060479E+02      1.912799E+02
              94     LS     -3.795005E-02     -4.554007E+01              3113    LS     -2.846254E+02     -1.778909E+02
              95     LS     -1.964539E-02     -2.357447E+01              3114    LS     -1.473405E+02     -9.208778E+01
              96     LS      3.002778E-02      3.603334E+01              3115    LS      2.252084E+02      1.407552E+02
      *** LABEL NOTATIONS:  LS = LIFTING SURFACE,  ZIB = Z INTERFERENCE BODY ELEMENT,  ZSB = Z SLENDER BODY ELEMENT,
                                                   YIB = Y INTERFERENCE BODY ELEMENT,  YSB = Y SLENDER BODY ELEMENT.

  FULL-SPAN MODEL                                                                                      SUBCASE 4

                            A E R O S T A T I C   D A T A   R E C O V E R Y   O U T P U T   T A B L E
                                                 AEROELASTIC TRIM VARIABLES
                                                TRIM VARIABLE    VALUE OF UX

                                                   ANGLEA        3.151200E-03
                                                   PITCH         0.000000E+00
                                                   URDD3        -8.659549E+00
                                                   URDD5         5.768343E-01
                                                   ELEV          4.363320E-01
                                                   SIDES         0.000000E+00
                                                   YAW           1.135192E-19
                                                   ROLL         -1.695235E-19
                                                   URDD2         3.127156E+00
                                                   URDD4         5.235149E-01
                                                   URDD6        -5.281315E-01
                                                   AILERON       0.000000E+00
                                                   RUDDER        4.363320E-01

                            A E R O S T A T I C   D A T A   R E C O V E R Y   O U T P U T   T A B L E
                                     MACH = 9.000000E-01                  Q = 1.200000E+03
                                                                                   AERODYNAMIC FORCES
      AERODYNAMIC           AERODYNAMIC PRES.    AERODYNAMIC
             GRID    LABEL     COEFFICIENTS         PRESSURES          EXTERNAL ID  LABEL  NORMAL FORCES(T3)   MOMENTS(R2)
               1     LS      3.127665E+00      3.753198E+03              1000    LS      2.345749E+04      1.466093E+04
               2     LS      5.400828E-01      6.480993E+02              1001    LS      4.050621E+03      2.531638E+03
               3     LS      1.769049E-01      2.122858E+02              1002    LS      1.326786E+03      8.292416E+02
               4     LS      9.641417E-02      1.156970E+02              1003    LS      7.231063E+02      4.519414E+02
               5     LS      2.476894E+00      2.972273E+03              1004    LS      1.857671E+04      1.161044E+04
               6     LS      3.860235E-01      4.632282E+02              1005    LS      2.895176E+03      1.809485E+03
               7     LS      1.326031E-01      1.591237E+02              1006    LS      9.945233E+02      6.215770E+02
               8     LS      8.484723E-02      1.018167E+02              1007    LS      6.363542E+02      3.977214E+02
               9     LS     -2.170004E+00     -2.604005E+03              1100    LS     -1.627503E+04     -1.017190E+04
              10     LS     -4.091441E-01     -4.909729E+02              1101    LS     -3.068581E+03     -1.917863E+03
              11     LS     -5.153607E-02     -6.184329E+01              1102    LS     -3.865206E+02     -2.415754E+02
              12     LS      2.604646E-01      3.125575E+02              1103    LS      1.953484E+03      1.220927E+03
              13     LS     -1.106834E+00     -1.328201E+03              1104    LS     -8.301254E+03     -5.188284E+03
              14     LS     -5.150145E-01     -6.180175E+02              1105    LS     -3.862609E+03     -2.414131E+03
              15     LS     -1.648353E-01     -1.978024E+02              1106    LS     -1.236265E+03     -7.726657E+02
              16     LS      1.409162E-02      1.690994E+01              1107    LS      1.056871E+02      6.605445E+01
              17     LS      1.700471E+00      2.040565E+03              1108    LS      1.275353E+04      7.970957E+03
              18     LS     -1.818285E-01     -2.181942E+02              1109    LS     -1.363714E+03     -8.523212E+02
              19     LS     -1.830603E-01     -2.196723E+02              1110    LS     -1.372952E+03     -8.580950E+02
              20     LS     -8.198647E-02     -9.838377E+01              1111    LS     -6.148986E+02     -3.843116E+02
              21     LS      1.153930E+00      1.384716E+03              1112    LS      8.654474E+03      5.409046E+03
              22     LS      2.310237E-01      2.772285E+02              1113    LS      1.732678E+03      1.082924E+03
              23     LS     -7.476046E-02     -8.971255E+01              1114    LS     -5.607034E+02     -3.504396E+02
              24     LS     -6.853464E-02     -8.224157E+01              1115    LS     -5.140098E+02     -3.212561E+02
              25     LS      8.178837E-01      9.814605E+02              1116    LS      6.134128E+03      3.833830E+03
              26     LS      3.208675E-01      3.850410E+02              1117    LS      2.406507E+03      1.504067E+03
              27     LS      5.670957E-02      6.805148E+01              1118    LS      4.253217E+02      2.658261E+02
              28     LS     -3.194197E-02     -3.833036E+01              1119    LS     -2.395647E+02     -1.497280E+02
              29     LS      6.001082E-01      7.201298E+02              1120    LS      4.500812E+03      2.813007E+03
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Listing 7-21 Output for FSW Airplane in Unsymmetric Maneuvers (Continued)

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        30    LS       2.867484E-01      3.440981E+02             1121   LS      2.150613E+03      1.344133E+03
        31    LS       1.240202E-01      1.488243E+02             1122   LS      9.301517E+02      5.813448E+02
        32    LS       1.601115E-02      1.921338E+01             1123   LS      1.200836E+02      7.505225E+01
        33    LS       4.306050E-01      5.167260E+02             1124   LS      3.229537E+03      2.018461E+03
        34    LS       2.209344E-01      2.651212E+02             1125   LS      1.657008E+03      1.035630E+03
        35    LS       1.299042E-01      1.558850E+02             1126   LS      9.742812E+02      6.089257E+02
        36    LS       4.789853E-02      5.747823E+01             1127   LS      3.592390E+02      2.245244E+02
        37    LS       2.675137E-01      3.210165E+02             1128   LS      2.006353E+03      1.253971E+03
        38    LS       1.388383E-01      1.666059E+02             1129   LS      1.041287E+03      6.508043E+02
        39    LS       9.473918E-02      1.136870E+02             1130   LS      7.105438E+02      4.440899E+02
        40    LS       5.058339E-02      6.070007E+01             1131   LS      3.793754E+02      2.371096E+02
        41    LS       2.476673E+00      2.972008E+03             2000   LS      1.857505E+04      1.160941E+04
        42    LS       3.857210E-01      4.628652E+02             2001   LS      2.892907E+03      1.808067E+03
        43    LS       1.318253E-01      1.581903E+02             2002   LS      9.886895E+02      6.179309E+02
        44    LS       8.277810E-02      9.933372E+01             2003   LS      6.208358E+02      3.880224E+02
        45    LS       3.127570E+00      3.753083E+03             2004   LS      2.345677E+04      1.466048E+04
        46    LS       5.399531E-01      6.479437E+02             2005   LS      4.049648E+03      2.531030E+03
        47    LS       1.765791E-01      2.118949E+02             2006   LS      1.324343E+03      8.277144E+02
        48    LS       9.560930E-02      1.147312E+02             2007   LS      7.170698E+02      4.481686E+02
        49    LS       2.365708E-01      2.838850E+02             2100   LS      1.774281E+03      1.108926E+03
        50    LS       1.260567E-01      1.512681E+02             2101   LS      9.454256E+02      5.908911E+02
        51    LS       8.619065E-02      1.034288E+02             2102   LS      6.464299E+02      4.040187E+02
        52    LS       4.422990E-02      5.307588E+01             2103   LS      3.317242E+02      2.073277E+02
        53    LS       3.865022E-01      4.638026E+02             2104   LS      2.898766E+03      1.811729E+03
        54    LS       2.022270E-01      2.426724E+02             2105   LS      1.516703E+03      9.479393E+02
        55    LS       1.174357E-01      1.409229E+02             2106   LS      8.807682E+02      5.504802E+02
        56    LS       3.880361E-02      4.656433E+01             2107   LS      2.910271E+02      1.818919E+02
        57    LS       5.475923E-01      6.571108E+02             2108   LS      4.106942E+03      2.566839E+03
        58    LS       2.645937E-01      3.175124E+02             2109   LS      1.984453E+03      1.240283E+03
        59    LS       1.086402E-01      1.303683E+02             2110   LS      8.148018E+02      5.092512E+02
        60    LS       3.197597E-03      3.837116E+00             2111   LS      2.398198E+01      1.498874E+01
        61    LS       7.601801E-01      9.122161E+02             2112   LS      5.701351E+03      3.563344E+03
        62    LS       2.962995E-01      3.555594E+02             2113   LS      2.222246E+03      1.388904E+03
        63    LS       3.752650E-02      4.503180E+01             2114   LS      2.814487E+02      1.759054E+02
        64    LS      -5.221706E-02     -6.266048E+01             2115   LS     -3.916280E+02     -2.447675E+02
        65    LS       1.093825E+00      1.312590E+03             2116   LS      8.203690E+03      5.127306E+03
        66    LS       2.045947E-01      2.455137E+02             2117   LS      1.534460E+03      9.590377E+02
        67    LS      -1.020614E-01     -1.224737E+02             2118   LS     -7.654608E+02     -4.784130E+02
        68    LS      -1.066064E-01     -1.279277E+02             2119   LS     -7.995480E+02     -4.997176E+02
        69    LS       1.641414E+00      1.969697E+03             2120   LS      1.231061E+04      7.694129E+03
        70    LS      -2.116487E-01     -2.539784E+02             2121   LS     -1.587365E+03     -9.921031E+02
        71    LS      -2.304658E-01     -2.765590E+02             2122   LS     -1.728494E+03     -1.080309E+03
        72    LS      -1.621420E-01     -1.945704E+02             2123   LS     -1.216065E+03     -7.600410E+02
        73    LS      -1.154681E+00     -1.385617E+03             2124   LS     -8.660106E+03     -5.412566E+03
        74    LS      -5.556432E-01     -6.667719E+02             2125   LS     -4.167324E+03     -2.604577E+03
        75    LS      -2.661954E-01     -3.194345E+02             2126   LS     -1.996466E+03     -1.247792E+03
        76    LS      -1.939341E-01     -2.327210E+02             2127   LS     -1.454506E+03     -9.090663E+02
        77    LS      -2.209841E+00     -2.651810E+03             2128   LS     -1.657381E+04     -1.035863E+04
        78    LS      -4.982656E-01     -5.979187E+02             2129   LS     -3.736992E+03     -2.335620E+03
        79    LS      -2.723013E-01     -3.267616E+02             2130   LS     -2.042260E+03     -1.276412E+03
        80    LS      -3.711098E-01     -4.453317E+02             2131   LS     -2.783323E+03     -1.739577E+03
        81    LS       1.276761E-01      1.532113E+02             3100   LS      9.575705E+02      5.984816E+02
        82    LS       2.003490E-01      2.404188E+02             3101   LS      1.502618E+03      9.391360E+02
        83    LS       4.230284E-01      5.076341E+02             3102   LS      3.172713E+03      1.982946E+03
        84    LS       1.376074E+00      1.651289E+03             3103   LS      1.032055E+04      6.450348E+03
        85    LS       1.241964E-01      1.490357E+02             3104   LS      9.314728E+02      5.821705E+02
        86    LS       2.328381E-01      2.794058E+02             3105   LS      1.746286E+03      1.091429E+03
        87    LS       5.256876E-01      6.308252E+02             3106   LS      3.942657E+03      2.464161E+03
        88    LS       1.658361E+00      1.990034E+03             3107   LS      1.243771E+04      7.773571E+03
        89    LS       9.451665E-02      1.134200E+02             3108   LS      7.088749E+02      4.430468E+02
        90    LS       2.021007E-01      2.425209E+02             3109   LS      1.515755E+03      9.473472E+02
        91    LS       4.974560E-01      5.969472E+02             3110   LS      3.730920E+03      2.331825E+03
        92    LS       1.704293E+00      2.045152E+03             3111   LS      1.278220E+04      7.988874E+03
        93    LS       6.307691E-02      7.569229E+01             3112   LS      4.730768E+02      2.956730E+02
        94    LS       1.498650E-01      1.798380E+02             3113   LS      1.123987E+03      7.024921E+02
        95    LS       3.874162E-01      4.648994E+02             3114   LS      2.905621E+03      1.816013E+03
        96    LS       1.561356E+00      1.873627E+03             3115   LS      1.171017E+04      7.318855E+03
 *** LABEL NOTATIONS:  LS = LIFTING SURFACE,  ZIB = Z INTERFERENCE BODY ELEMENT,  ZSB = Z SLENDER BODY ELEMENT,
                                              YIB = Y INTERFERENCE BODY ELEMENT,  YSB = Y SLENDER BODY ELEMENT.
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Listing 7-21 Output for FSW Airplane in Unsymmetric Maneuvers (Continued)

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FULL-SPAN MODEL                                                                                     SUBCASE 5

                              A E R O S T A T I C   D A T A   R E C O V E R Y   O U T P U T   T A B L E
                                                   AEROELASTIC TRIM VARIABLES
                                                  TRIM VARIABLE    VALUE OF UX

                                                    ANGLEA        5.518734E-03
                                                    PITCH         2.222000E-04
                                                    URDD3        -1.917000E+00
                                                    URDD5         0.000000E+00
                                                    ELEV          3.402172E-02
                                                    SIDES         4.590776E-04
                                                    YAW           5.435000E-04
                                                    ROLL         -3.222000E-05
                                                    URDD2         0.000000E+00
                                                    URDD4         0.000000E+00
                                                    URDD6        -1.099301E-28
                                                    AILERON      -5.857044E-05
                                                    RUDDER       -1.940631E-04

                              A E R O S T A T I C   D A T A   R E C O V E R Y   O U T P U T   T A B L E
                                       MACH = 9.000000E-01                Q = 1.200000E+03

                                                                                AERODYNAMIC FORCES
   AERODYNAMIC          AERODYNAMIC PRES.    AERODYNAMIC
         GRID    LABEL    COEFFICIENTS        PRESSURES          EXTERNAL ID  LABEL  NORMAL FORCES(T3)   MOMENTS(R2)
            1     LS      2.861119E-01       3.433343E+02              1000    LS      2.145839E+03      1.341150E+03
            2     LS      5.328529E-02       6.394235E+01              1001    LS      3.996397E+02      2.497748E+02
            3     LS      2.301040E-02       2.761248E+01              1002    LS      1.725780E+02      1.078613E+02
            4     LS      1.913792E-02       2.296551E+01              1003    LS      1.435344E+02      8.970901E+01
            5     LS      2.264952E-01       2.717943E+02              1004    LS      1.698714E+03      1.061696E+03
            6     LS      3.838074E-02       4.605689E+01              1005    LS      2.878556E+02      1.799097E+02
            7     LS      1.761722E-02       2.114066E+01              1006    LS      1.321291E+02      8.258070E+01
            8     LS      1.684681E-02       2.021617E+01              1007    LS      1.263511E+02      7.896941E+01
            9     LS     -7.093064E-02      -8.511677E+01              1100    LS     -5.319798E+02     -3.324874E+02
           10     LS     -6.260771E-03      -7.512926E+00              1101    LS     -4.695579E+01     -2.934737E+01
           11     LS     -3.741469E-04      -4.489763E-01              1102    LS     -2.806102E+00     -1.753814E+00
           12     LS      4.836466E-04       5.803760E-01              1103    LS      3.627350E+00      2.267093E+00
           13     LS      1.021406E-02       1.225687E+01              1104    LS      7.660545E+01      4.787841E+01
           14     LS     -4.882480E-03      -5.858975E+00              1105    LS     -3.661860E+01     -2.288662E+01
           15     LS      1.086909E-04       1.304290E-01              1106    LS      8.151815E-01      5.094885E-01
           16     LS     -1.217015E-03      -1.460418E+00              1107    LS     -9.127609E+00     -5.704756E+00
           17     LS      2.703598E-01       3.244317E+02              1108    LS      2.027698E+03      1.267311E+03
           18     LS      3.029836E-02       3.635804E+01              1109    LS      2.272377E+02      1.420236E+02
           19     LS      5.322694E-03       6.387233E+00              1110    LS      3.992020E+01      2.495013E+01
           20     LS     -3.554577E-03      -4.265492E+00              1111    LS     -2.665932E+01     -1.666208E+01
           21     LS      2.061523E-01       2.473827E+02              1112    LS      1.546142E+03      9.663388E+02
           22     LS      6.693786E-02       8.032543E+01              1113    LS      5.020340E+02      3.137712E+02
           23     LS      1.915643E-02       2.298771E+01              1114    LS      1.436732E+02      8.979576E+01
           24     LS      4.908526E-03       5.890231E+00              1115    LS      3.681395E+01      2.300871E+01
           25     LS      1.628166E-01       1.953799E+02              1116    LS      1.221124E+03      7.632026E+02
           26     LS      7.085872E-02       8.503046E+01              1117    LS      5.314404E+02      3.321502E+02
           27     LS      3.116174E-02       3.739408E+01              1118    LS      2.337130E+02      1.460706E+02
           28     LS      1.077477E-02       1.292973E+01              1119    LS      8.081078E+01      5.050674E+01
           29     LS      1.301445E-01       1.561734E+02              1120    LS      9.760836E+02      6.100522E+02
           30     LS      6.202522E-02       7.443027E+01              1121    LS      4.651892E+02      2.907432E+02
           31     LS      3.509580E-02       4.211496E+01              1122    LS      2.632185E+02      1.645115E+02
           32     LS      1.540234E-02       1.848281E+01              1123    LS      1.155175E+02      7.219846E+01
           33     LS      1.000322E-01       1.200386E+02              1124    LS      7.502413E+02      4.689008E+02
           34     LS      4.884014E-02       5.860817E+01              1125    LS      3.663011E+02      2.289382E+02
           35     LS      3.171773E-02       3.806128E+01              1126    LS      2.378830E+02      1.486768E+02
           36     LS      1.714549E-02       2.057459E+01              1127    LS      1.285912E+02      8.036951E+01
           37     LS      6.579221E-02       7.895065E+01              1128    LS      4.934416E+02      3.084010E+02
           38     LS      3.159373E-02       3.791247E+01              1129    LS      2.369529E+02      1.480956E+02
           39     LS      2.216355E-02       2.659625E+01              1130    LS      1.662266E+02      1.038916E+02
           40     LS      1.432258E-02       1.718709E+01              1131    LS      1.074193E+02      6.713708E+01
           41     LS      2.265358E-01       2.718430E+02              2000    LS      1.699019E+03      1.061887E+03
           42     LS      3.838381E-02       4.606057E+01              2001    LS      2.878786E+02      1.799241E+02
           43     LS      1.762072E-02       2.114486E+01              2002    LS      1.321554E+02      8.259712E+01
           44     LS      1.685473E-02       2.022567E+01              2003    LS      1.264104E+02      7.900652E+01
           45     LS      2.861291E-01       3.433549E+02              2004    LS      2.145969E+03      1.341230E+03
           46     LS      5.328677E-02       6.394413E+01              2005    LS      3.996508E+02      2.497817E+02
           47     LS      2.301185E-02       2.761422E+01              2006    LS      1.725889E+02      1.078680E+02
           48     LS      1.914092E-02       2.296910E+01              2007    LS      1.435569E+02      8.972305E+01
           49     LS      6.605995E-02       7.927194E+01              2100    LS      4.954496E+02      3.096560E+02
           50     LS      3.166926E-02       3.800311E+01              2101    LS      2.375195E+02      1.484497E+02
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Listing 7-21 Output for FSW Airplane in Unsymmetric Maneuvers (Continued)

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                51    LS     2.215817E-02       2.658980E+01              2102   LS     1.661862E+02      1.038664E+02
                52    LS     1.395896E-02       1.675075E+01              2103   LS     1.046922E+02      6.543263E+01
                53    LS     1.003667E-01       1.204400E+02              2104   LS     7.527501E+02      4.704688E+02
                54    LS     4.892272E-02       5.870726E+01              2105   LS     3.669204E+02      2.293253E+02
                55    LS     3.165903E-02       3.799084E+01              2106   LS     2.374428E+02      1.484018E+02
                56    LS     1.671512E-02       2.005814E+01              2107   LS     1.253634E+02      7.835211E+01
                57    LS     1.304858E-01       1.565829E+02              2108   LS     9.786434E+02      6.116521E+02
                58    LS     6.208887E-02       7.450665E+01              2109   LS     4.656665E+02      2.910417E+02
                59    LS     3.500419E-02       4.200503E+01              2110   LS     2.625314E+02      1.640822E+02
                60    LS     1.496621E-02       1.795945E+01              2111   LS     1.122466E+02      7.015411E+01
                61    LS     1.631303E-01       1.957563E+02              2112   LS     1.223477E+03      7.646732E+02
                62    LS     7.089952E-02       8.507942E+01              2113   LS     5.317464E+02      3.323416E+02
                63    LS     3.106449E-02       3.727739E+01              2114   LS     2.329837E+02      1.456148E+02
                64    LS     1.039011E-02       1.246813E+01              2115   LS     7.792579E+01      4.870362E+01
                65    LS     2.064209E-01       2.477051E+02              2116   LS     1.548157E+03      9.675981E+02
                66    LS     6.696400E-02       8.035680E+01              2117   LS     5.022300E+02      3.138937E+02
                67    LS     1.908629E-02       2.290354E+01              2118   LS     1.431472E+02      8.946697E+01
                68    LS     4.826819E-03       5.792183E+00              2119   LS     3.620115E+01      2.262572E+01
                69    LS     2.705799E-01       3.246959E+02              2120   LS     2.029349E+03      1.268343E+03
                70    LS     3.032573E-02       3.639087E+01              2121   LS     2.274430E+02      1.421519E+02
                71    LS     5.302770E-03       6.363324E+00              2122   LS     3.977078E+01      2.485674E+01
                72    LS    -3.607364E-03      -4.328837E+00              2123   LS    -2.705524E+01     -1.690952E+01
                73    LS     1.033240E-02       1.239889E+01              2124   LS     7.749303E+01      4.843315E+01
                74    LS    -4.811152E-03      -5.773383E+00              2125   LS    -3.608364E+01     -2.255228E+01
                75    LS     8.433375E-05       1.012005E-01              2126   LS     6.325033E-01      3.953146E-01
                76    LS    -1.311935E-03      -1.574322E+00              2127   LS    -9.839513E+00     -6.149696E+00
                77    LS    -7.074601E-02      -8.489522E+01              2128   LS    -5.305951E+02     -3.316219E+02
                78    LS    -6.128056E-03      -7.353667E+00              2129   LS    -4.596042E+01     -2.872526E+01
                79    LS    -5.604268E-04      -6.725122E-01              2130   LS    -4.203201E+00     -2.627001E+00
                80    LS     4.032504E-04       4.839004E-01              2131   LS     3.024378E+00      1.890236E+00
                81    LS     5.245054E-05       6.294065E-02              3100   LS     3.933791E-01      2.458619E-01
                82    LS     2.913060E-04       3.495672E-01              3101   LS     2.184795E+00      1.365497E+00
                83    LS     1.869427E-04       2.243313E-01              3102   LS     1.402070E+00      8.762940E-01
                84    LS    -3.276875E-04      -3.932250E-01              3103   LS    -2.457657E+00     -1.536036E+00
                85    LS    -1.470681E-04      -1.764817E-01              3104   LS    -1.103011E+00     -6.893816E-01
                86    LS     3.402973E-04       4.083568E-01              3105   LS     2.552230E+00      1.595144E+00
                87    LS     2.631754E-04       3.158105E-01              3106   LS     1.973816E+00      1.233635E+00
                88    LS    -3.483750E-04      -4.180500E-01              3107   LS    -2.612812E+00     -1.633008E+00
                89    LS    -3.725851E-04      -4.471021E-01              3108   LS    -2.794388E+00     -1.746493E+00
                90    LS     3.075220E-04       3.690264E-01              3109   LS     2.306415E+00      1.441509E+00
                91    LS     3.081779E-04       3.698135E-01              3110   LS     2.311334E+00      1.444584E+00
                92    LS    -3.215809E-04      -3.858970E-01              3111   LS    -2.411856E+00     -1.507410E+00
                93    LS    -5.156262E-04      -6.187514E-01              3112   LS    -3.867196E+00     -2.416998E+00
                94    LS     2.061618E-04       2.473941E-01              3113   LS     1.546213E+00      9.663833E-01
                95    LS     3.306819E-04       3.968183E-01              3114   LS     2.480114E+00      1.550071E+00
                96    LS    -2.537928E-04      -3.045513E-01              3115   LS    -1.903446E+00     -1.189654E+00
        *** LABEL NOTATIONS:  LS = LIFTING SURFACE,  ZIB = Z INTERFERENCE BODY ELEMENT,  ZSB = Z SLENDER BODY ELEMENT,
                                                     YIB = Y INTERFERENCE BODY ELEMENT,  YSB = Y SLENDER BODY ELEMENT.

    FULL-SPAN MODEL                                                                                         SUBCASE 1

                                       D I S P L A C E M E N T   V E C T O R

    POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
          90      G      0.0            0.0            0.0            0.0            0.0            0.0
          97      G      0.0            0.0           -6.283592E-03  -1.375565E-12  -6.400195E-04   0.0
          98      G      0.0            0.0           -8.833975E-04  -1.375565E-12  -3.400193E-04   0.0
          99      G     -1.190659E-19   3.067929E-18  -1.016795E-03   1.375565E-12   4.200575E-04   1.201939E-18
         100      G     -2.880183E-19  -4.705983E-12  -1.138205E-02   6.877825E-12   1.809385E-03  -1.411799E-12
         110      G      7.058997E-12  -6.304723E-13  -2.536639E-03   8.045118E-04   2.742208E-03  -1.411799E-12
         111      G      7.058997E-12   2.899027E-12   4.318881E-03   8.045118E-04   2.742208E-03  -1.411799E-12
         112      G      7.058997E-12  -4.159971E-12  -9.392160E-03   8.045118E-04   2.742208E-03  -1.411799E-12
         120      G      2.117699E-11   7.520553E-12   2.762073E-02   1.370994E-03   3.500449E-03  -1.411799E-12
         121      G      2.117699E-11   1.105005E-11   3.637186E-02   1.370994E-03   3.500449E-03  -1.411799E-12
         122      G      2.117699E-11   3.991054E-12   1.886961E-02   1.370994E-03   3.500449E-03  -1.411799E-12
         210      G     -7.058998E-12  -6.304725E-13  -2.536639E-03  -8.045118E-04   2.742208E-03  -1.411799E-12
         211      G     -7.058998E-12   2.899026E-12   4.318881E-03  -8.045118E-04   2.742208E-03  -1.411799E-12
         212      G     -7.058998E-12  -4.159971E-12  -9.392160E-03  -8.045118E-04   2.742208E-03  -1.411799E-12
         220      G     -2.117699E-11   7.520553E-12   2.762073E-02  -1.370994E-03   3.500449E-03  -1.411799E-12
         221      G     -2.117699E-11   1.105005E-11   3.637186E-02  -1.370994E-03   3.500449E-03  -1.411799E-12
         222      G     -2.117699E-11   3.991054E-12   1.886961E-02  -1.370994E-03   3.500449E-03  -1.411799E-12
         310      G      9.055031E-03  -4.356467E-11  -1.661024E-02   5.856540E-12   1.811563E-03  -3.442336E-12
         311      G      9.055031E-03  -3.495883E-11  -1.208133E-02   5.856540E-12   1.811563E-03  -3.442336E-12
         312      G      9.055031E-03  -5.217051E-11  -2.113914E-02   5.856540E-12   1.811563E-03  -3.442336E-12
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Listing 7-21 Output for FSW Airplane in Unsymmetric Maneuvers (Continued)

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FULL-SPAN MODEL                                                                                     SUBCASE 2

                                   D I S P L A C E M E N T   V E C T O R

POINT ID.   TYPE         T1             T2             T3             R1             R2             R3
       90      G      0.0            0.0            0.0            0.0            0.0            0.0
       97      G      0.0            2.666585E-20  -3.008065E-02   6.577025E-05  -3.066049E-03  -2.635213E-21
       98      G      0.0            4.078307E-21  -4.220161E-03   6.577025E-05  -1.626049E-03  -1.505836E-21
       99      G     -6.025291E-19   1.364871E-17  -4.840320E-03  -6.577025E-05   1.998144E-03   5.305651E-18
      100      G     -1.536097E-18   2.024627E-04  -5.408836E-02  -3.288513E-04   8.593932E-03   6.073881E-05
      110      G     -3.036941E-04   2.712499E-05  -7.486501E-04   3.023528E-03   2.273834E-02   6.073881E-05
      111      G     -3.036941E-04  -1.247220E-04   5.609721E-02   3.023528E-03   2.273834E-02   6.073881E-05
      112      G     -3.036941E-04   1.789720E-04  -5.759451E-02   3.023528E-03   2.273834E-02   6.073881E-05
      120      G     -9.110822E-04  -3.235506E-04   2.282894E-01   5.134988E-03   4.084643E-02   6.073881E-05
      121      G     -9.110822E-04  -4.753976E-04   3.304055E-01   5.134988E-03   4.084643E-02   6.073881E-05
      122      G     -9.110822E-04  -1.717035E-04   1.261733E-01   5.134988E-03   4.084643E-02   6.073881E-05
      210      G      3.036941E-04   2.712499E-05  -2.336226E-02  -4.636744E-03   3.299792E-03   6.073881E-05
      211      G      3.036941E-04  -1.247220E-04  -1.511278E-02  -4.636744E-03   3.299792E-03   6.073881E-05
      212      G      3.036941E-04   1.789720E-04  -3.161174E-02  -4.636744E-03   3.299792E-03   6.073881E-05
      220      G      9.110822E-04  -3.235506E-04   3.411017E-02  -7.914126E-03  -7.652436E-03   6.073881E-05
      221      G      9.110822E-04  -4.753976E-04   1.497908E-02  -7.914126E-03  -7.652436E-03   6.073881E-05
      222      G      9.110822E-04  -1.717035E-04   5.324126E-02  -7.914126E-03  -7.652436E-03   6.073881E-05
      310      G      4.300858E-02   1.986964E-03  -7.892064E-02  -1.676221E-04   8.604390E-03   3.296162E-04
      311      G      4.300858E-02   1.162923E-03  -5.740966E-02  -1.676221E-04   8.604390E-03   3.296162E-04
      312      G      4.300858E-02   2.811004E-03  -1.004316E-01  -1.676221E-04   8.604390E-03   3.296162E-04
FULL-SPAN MODEL                                                                                     SUBCASE 3

                                   D I S P L A C E M E N T   V E C T O R

POINT ID.   TYPE         T1             T2             T3             R1             R2             R3
       90      G      0.0            0.0            0.0            0.0            0.0            0.0
       97      G      0.0            2.666585E-20  -3.008065E-02  -4.769861E-06  -3.066049E-03  -2.635213E-21
       98      G      0.0            4.078307E-21  -4.220161E-03  -4.769861E-06  -1.626048E-03  -1.505836E-21
       99      G     -5.744701E-19   1.421246E-17  -4.840320E-03   4.769861E-06   1.998144E-03   5.558820E-18
      100      G     -1.792114E-18   3.694712E-05  -5.408835E-02   2.384930E-05   8.593931E-03   1.108414E-05
      110      G     -5.542068E-05   4.949999E-06  -5.806080E-03   3.959074E-03   1.712622E-02   1.108414E-05
      111      G     -5.542068E-05  -2.276034E-05   3.700949E-02   3.959074E-03   1.712622E-02   1.108414E-05
      112      G     -5.542068E-05   3.266034E-05  -4.862164E-02   3.959074E-03   1.712622E-02   1.108414E-05
      120      G     -1.662620E-04  -5.904427E-05   1.850598E-01   6.813272E-03   2.813625E-02   1.108414E-05
      121      G     -1.662620E-04  -8.675460E-05   2.554004E-01   6.813272E-03   2.813625E-02   1.108414E-05
      122      G     -1.662620E-04  -3.133393E-05   1.147191E-01   6.813272E-03   2.813625E-02   1.108414E-05
      210      G      5.542068E-05   4.949999E-06  -1.830482E-02  -3.701198E-03   8.911909E-03   1.108414E-05
      211      G      5.542068E-05  -2.276034E-05   3.974949E-03  -3.701198E-03   8.911909E-03   1.108414E-05
      212      G      5.542068E-05   3.266034E-05  -4.058459E-02  -3.701198E-03   8.911909E-03   1.108414E-05
      220      G      1.662620E-04  -5.904427E-05   7.733982E-02  -6.235841E-03   5.057744E-03   1.108414E-05
      221      G      1.662620E-04  -8.675460E-05   8.998418E-02  -6.235841E-03   5.057744E-03   1.108414E-05
      222      G      1.662620E-04  -3.133393E-05   6.469546E-02  -6.235841E-03   5.057744E-03   1.108414E-05
      310      G      4.300858E-02  -3.824739E-05  -7.892063E-02   1.167260E-05   8.604389E-03  -4.227489E-06
      311      G      4.300858E-02  -2.767867E-05  -5.740966E-02   1.167260E-05   8.604389E-03  -4.227489E-06
      312      G      4.300858E-02  -4.881611E-05  -1.004316E-01   1.167260E-05   8.604389E-03  -4.227489E-06
FULL-SPAN MODEL                                                                                     SUBCASE 4

                                   D I S P L A C E M E N T   V E C T O R

POINT ID.   TYPE         T1             T2             T3             R1             R2             R3
       90      G      0.0            0.0            0.0            0.0            0.0            0.0
       97      G      0.0            3.689642E-02  -9.810241E-02   4.976837E-07  -1.027909E-02  -3.703719E-03
       98      G      0.0            5.408786E-03  -1.262355E-02   4.976837E-07  -5.085471E-03  -2.038853E-03
       99      G     -2.503621E-07   6.655405E-03  -1.226304E-02  -4.976837E-07   4.869168E-03   2.786824E-03
      100      G     -7.510864E-07   6.434543E-02  -1.179144E-01  -2.488418E-06   1.719605E-02   8.572550E-03
      110      G     -4.260102E-02   3.969252E-02  -2.856540E-02   9.215011E-03   2.708838E-02   8.480265E-03
      111      G     -4.260102E-02   1.849186E-02   3.915555E-02   9.215011E-03   2.708838E-02   8.480265E-03
      112      G     -4.260102E-02   6.089319E-02  -9.628636E-02   9.215011E-03   2.708838E-02   8.480265E-03
      120      G     -1.267980E-01  -8.976239E-03   2.952354E-01   1.627373E-02   3.549792E-02   8.393090E-03
      121      G     -1.267980E-01  -2.995897E-02   3.839802E-01   1.627373E-02   3.549792E-02   8.393090E-03
      122      G     -1.267980E-01   1.200649E-02   2.064906E-01   1.627373E-02   3.549792E-02   8.393090E-03
      210      G      4.259951E-02   3.969252E-02  -5.112616E-02  -3.131837E-03   2.337301E-02   8.480265E-03
      211      G      4.259951E-02   1.849186E-02   7.306375E-03  -3.131837E-03   2.337301E-02   8.480265E-03
      212      G      4.259951E-02   6.089319E-02  -1.095587E-01  -3.131837E-03   2.337301E-02   8.480265E-03
      220      G      1.267965E-01  -8.976239E-03   1.504254E-01  -5.904732E-03   2.866016E-02   8.393090E-03
      221      G      1.267965E-01  -2.995897E-02   2.220758E-01  -5.904732E-03   2.866016E-02   8.393090E-03
      222      G      1.267965E-01   1.200649E-02   7.877505E-02  -5.904732E-03   2.866016E-02   8.393090E-03
      310      G      8.589272E-02   9.100250E-02  -1.675051E-01   8.392542E-04   1.716842E-02   1.108163E-02
      311      G      8.589272E-02   6.329843E-02  -1.245840E-01   8.392542E-04   1.716842E-02   1.108163E-02
      312      G      8.589272E-02   1.187066E-01  -2.104261E-01   8.392542E-04   1.716842E-02   1.108163E-02
```

Listing 7-21 Output for FSW Airplane in Unsymmetric Maneuvers (Continued)

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 FULL-SPAN MODEL                                                                                    SUBCASE 5

                                   D I S P L A C E M E N T   V E C T O R

 POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
        90      G      0.0            0.0            0.0            0.0            0.0            0.0
        97      G      0.0            1.351860E-29  -1.201605E-02  -8.181624E-09  -1.224698E-03  -1.335956E-30
        98      G      0.0            2.067551E-30  -1.686073E-03  -8.181624E-09  -6.495971E-04  -7.634034E-31
        99      G     -2.333323E-19   5.878382E-18  -1.934396E-03   8.181624E-09   7.985907E-04   2.304321E-18
       100      G     -5.120325E-19  -4.141365E-07  -2.161905E-02   4.090812E-08   3.435126E-03  -1.242409E-07
       110      G      6.212047E-07  -5.548402E-08  -4.819604E-03   1.530897E-03   5.202882E-03  -1.242409E-07
       111      G      6.212047E-07   2.551183E-07   8.187599E-03   1.530897E-03   5.202882E-03  -1.242409E-07
       112      G      6.212047E-07  -3.660864E-07  -1.782681E-02   1.530897E-03   5.202882E-03  -1.242409E-07
       120      G      1.863614E-06   6.618211E-07   5.243254E-02   2.607960E-03   6.632013E-03  -1.242409E-07
       121      G      1.863614E-06   9.724234E-07   6.901257E-02   2.607960E-03   6.632013E-03  -1.242409E-07
       122      G      1.863614E-06   3.512187E-07   3.585251E-02   2.607960E-03   6.632013E-03  -1.242409E-07
       210      G     -6.212047E-07  -5.548402E-08  -4.817418E-03  -1.530448E-03   5.205313E-03  -1.242409E-07
       211      G     -6.212047E-07   2.551183E-07   8.195865E-03  -1.530448E-03   5.205313E-03  -1.242409E-07
       212      G     -6.212047E-07  -3.660864E-07  -1.783070E-02  -1.530448E-03   5.205313E-03  -1.242409E-07
       220      G     -1.863614E-06   6.618211E-07   5.245187E-02  -2.607139E-03   6.638009E-03  -1.242409E-07
       221      G     -1.863614E-06   9.724234E-07   6.904689E-02  -2.607139E-03   6.638009E-03  -1.242409E-07
       222      G     -1.863614E-06   3.512187E-07   3.585685E-02  -2.607139E-03   6.638009E-03  -1.242409E-07
       310      G      1.719117E-02  -9.694116E-07  -3.154488E-02  -1.449587E-07   3.439302E-03  -4.514883E-07
       311      G      1.719117E-02   1.593091E-07  -2.294662E-02  -1.449587E-07   3.439302E-03  -4.514883E-07
       312      G      1.719117E-02  -2.098132E-06  -4.014314E-02  -1.449587E-07   3.439302E-03  -4.514883E-07
 FULL-SPAN MODEL                                                                                    SUBCASE 1

                         F O R C E S   I N   B A R   E L E M E N T S         ( C B A R )

ELEMENT         BEND-MOMENT END-A            BEND-MOMENT END-B               - SHEAR -               AXIAL
  ID.         PLANE 1       PLANE 2        PLANE 1       PLANE 2        PLANE 1       PLANE 2        FORCE          TORQUE
     101   -9.094947E-13  0.0           -3.000000E+04  0.0            3.000000E+03  0.0            0.0            1.572822E-16
     102   -3.000000E+04  0.0           -3.800382E+04  0.0            1.600763E+03  0.0            0.0            1.485610E-04
     103   -3.800382E+04 -1.103879E-10 -4.600763E+04 -9.730721E-11  1.600763E+03 -2.616130E-12 -1.371640E-10  1.485610E-04
     104   -4.600763E+04 -9.740170E-11 -9.292499E+04  1.219797E-04  4.691736E+03 -1.219798E-05 -9.731654E-11  2.971220E-04
     110    6.226683E+04  2.773295E-12  3.846394E+04  1.742006E-12  4.122783E+03  1.786245E-13 -3.755793E-14  1.756271E+04
     120    3.299180E+04  1.688287E-12  4.667687E+03  7.875740E-14  2.452940E+03  1.393894E-13 -1.877892E-14  8.084671E+03
     210    6.226683E+04 -5.611514E-11  3.846394E+04  1.703835E-12  4.122783E+03 -1.001454E-11 -6.691022E-12 -1.756271E+04
     220    3.299179E+04  1.485610E-12  4.667683E+03  5.972845E-14  2.452940E+03  1.234850E-13  1.829143E-14 -8.084670E+03
     310   -2.386749E+02  7.377408E-05  4.999999E+01  5.672844E-05 -4.999997E+01  2.952393E-06 -8.660255E+01 -9.825661E-05
 FULL-SPAN MODEL                                                                                    SUBCASE 2

                         F O R C E S   I N   B A R   E L E M E N T S         ( C B A R )

ELEMENT         BEND-MOMENT END-A            BEND-MOMENT END-B               - SHEAR -               AXIAL
  ID.         PLANE 1       PLANE 2        PLANE 1       PLANE 2        PLANE 1       PLANE 2        FORCE          TORQUE
     101     0.0          -6.310887E-30 -1.440000E+05 -9.757820E-14  1.440000E+04  9.757820E-15  0.0            0.0
     102   -1.440000E+05 -9.757820E-14 -1.812095E+05 -1.626303E-13  7.441901E+03  1.301043E-14  0.0           -7.103188E+03
     103   -1.812095E+05 -4.982818E-10 -2.184190E+05 -4.185348E-10  7.441901E+03 -1.594940E-11 -6.941134E-10 -7.103188E+03
     104   -2.184190E+05 -4.175447E-10 -4.411594E+05 -5.247833E+03  2.227404E+04  5.247834E+02 -5.377354E-10 -1.420638E+04
     110    4.939954E+05  2.364686E-11  3.699034E+05  2.889783E-11  2.149338E+04 -9.094947E-13  3.637979E-12  4.578346E+05
     120    2.884018E+05  2.364686E-11  1.828292E+05  7.893954E-12  9.142859E+03  1.364242E-12 -9.094947E-13  3.166696E+05
     210    9.845001E+04 -2.546585E-10 -4.600900E+03  6.565060E-11  1.784894E+04 -5.547918E-11 -7.821654E-11  2.917989E+05
     220    2.482422E+04  3.092282E-11 -1.390450E+05  7.293457E-12  1.419149E+04  2.046363E-12  9.094947E-13  2.408330E+05
     310   -1.145640E+03  1.301454E+04  2.400000E+02 -7.836728E+03 -2.399999E+02  3.611547E+03 -4.156923E+02  1.357362E+04
 FULL-SPAN MODEL                                                                                    SUBCASE 3

                         F O R C E S   I N   B A R   E L E M E N T S         ( C B A R )

 ELEMENT         BEND-MOMENT END-A            BEND-MOMENT END-B               - SHEAR -               AXIAL
  ID.         PLANE 1       PLANE 2        PLANE 1       PLANE 2        PLANE 1       PLANE 2        FORCE          TORQUE
     101   -7.275958E-12 -6.310887E-30 -1.440000E+05 -9.757820E-14  1.440000E+04  9.757820E-15  0.0            0.0
     102   -1.440000E+05 -9.757820E-14 -1.812095E+05 -1.626303E-13  7.441897E+03  1.301043E-14  0.0            5.151450E+02
     103   -1.812095E+05 -5.129836E-10 -2.184190E+05 -4.475806E-10  7.441897E+03 -1.308061E-11 -6.617895E-10  5.151450E+02
     104   -2.184190E+05 -4.507738E-10 -4.411593E+05 -9.576694E+02  2.227404E+04  9.576694E+01 -7.013626E-10  1.030290E+03
     110    3.863516E+05  1.637090E-11  2.782490E+05 -1.316580E-11  1.872393E+04  5.115908E-12  4.342837E-11  2.347611E+05
     120    2.440580E+05 -2.091838E-11  1.013483E+05  5.336470E-12  1.235902E+04 -2.273737E-12  2.148681E-11  1.755404E+05
     210    2.060938E+05 -4.908998E-10  8.705350E+04  1.851625E-10  2.061839E+04 -1.170974E-10 -1.305125E-10  6.872545E+04
     220    6.916809E+04 -3.137757E-11 -5.756406E+04  4.722849E-12  1.097533E+04 -3.126388E-12 -2.137313E-11  9.970392E+04
     310   -1.145640E+03 -3.366487E+03  2.400000E+02  4.837149E+02 -2.399999E+02 -6.668746E+02 -4.156923E+02 -8.378195E+02
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Listing 7-21 Output for FSW Airplane in Unsymmetric Maneuvers (Continued)

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 FULL-SPAN MODEL                                                                                    SUBCASE 4

                                 F O R C E S   I N   B A R   E L E M E N T S        ( C B A R )

ELEMENT        BEND-MOMENT END-A            BEND-MOMENT END-B              - SHEAR -               AXIAL
  ID.        PLANE 1       PLANE 2        PLANE 1       PLANE 2        PLANE 1       PLANE 2        FORCE          TORQUE
    101     0.0           0.0           -5.193619E+05 -1.438445E+05   5.193619E+04  1.438445E+04   0.0           -8.881784E-16
    102   -5.193619E+05 -1.438445E+05  -4.977316E+05 -2.084692E+05  -4.326061E+03  1.292495E+04   0.0           -5.374984E+01
    103   -4.977316E+05 -2.084692E+05  -4.761013E+05 -2.730940E+05  -4.326061E+03  1.292495E+04  -2.884171E+02 -5.374984E+01
    104   -4.761013E+05 -2.730940E+05  -7.565864E+05 -2.267928E+05   2.804851E+04 -4.630117E+03  -2.884171E+02 -1.074997E+02
    110    6.677701E+05  5.011036E+04   4.518922E+05  4.196039E+04   3.739116E+04  1.411615E+03  -1.868028E+04  1.713980E+05
    120    3.998546E+05  4.342184E+04   4.691892E+04  6.313428E+01   3.056513E+04  3.754975E+03  -9.340141E+03  8.126596E+04
    210    2.689082E+05  5.011036E+04   2.332628E+05  4.196039E+04   6.173956E+03  1.411615E+03   1.868028E+04 -1.638838E+05
    220    1.785490E+05  4.342184E+04   3.990443E+04  6.313428E+01   1.200698E+04  3.754975E+03   9.340141E+03 -6.911652E+04
    310    2.115105E+03 -4.594926E+05   2.776144E+02 -6.484483E+04   3.182628E+02 -6.835501E+04  -2.558681E+01  1.123146E+05
 FULL-SPAN MODEL                                                                                    SUBCASE 5

                                 F O R C E S   I N   B A R   E L E M E N T S        ( C B A R )

ELEMENT        BEND-MOMENT END-A            BEND-MOMENT END-B              - SHEAR -               AXIAL
  ID.        PLANE 1       PLANE 2        PLANE 1       PLANE 2        PLANE 1       PLANE 2        FORCE          TORQUE
    101   -3.637979E-12 -5.877472E-39  -5.751000E+04 -4.946854E-23   5.751000E+03  4.946854E-24   0.0            3.122502E-16
    102   -5.751000E+04 -4.946854E-23  -7.240934E+04 -8.244757E-23   2.979869E+03  6.595806E-24   0.0            8.836154E-01
    103   -7.240934E+04 -2.112840E-10  -8.730869E+04 -1.869028E-10   2.979869E+03 -4.876237E-12  -2.687988E-10  8.836154E-01
    104   -8.730869E+04 -1.855495E-10  -1.763447E+05  1.073442E+01   8.903599E+03 -1.073442E+00  -1.605313E-10  1.767231E+00
    110    1.183698E+05  5.293543E-12   7.299042E+04  3.319302E-12   7.859931E+03  3.419487E-13  -7.460699E-14  3.314685E+04
    120    6.259227E+04  3.204548E-12   8.739168E+03  1.380635E-13   4.663815E+03  2.655653E-13  -3.552714E-14  1.513669E+04
    210    1.184088E+05 -7.928591E-11   7.302909E+04 -2.660700E-11   7.859997E+03 -9.124257E-12  -2.545875E-11 -3.324602E+04
    220    6.261458E+04  2.838618E-12   8.780066E+03  1.823660E-13   4.662206E+03  2.300382E-13   3.197442E-14 -1.520753E+04
    310   -4.575398E+02 -6.756530E+00   9.585001E+01  9.408445E+00  -9.584995E+01 -2.799856E+00  -1.660171E+02 -1.629592E+01
 FULL-SPAN MODEL                                                                                    SUBCASE 1

                                 S T R E S S E S   I N   B A R   E L E M E N T S        ( C B A R )

  ELEMENT        SA1            SA2            SA3            SA4           AXIAL          SA-MAX         SA-MIN     M.S.-T
    ID.          SB1            SB2            SB3            SB4           STRESS         SB-MAX         SB-MIN     M.S.-C
 101     2.619346E-12   2.619346E-12  -2.619346E-12  -2.619346E-12   0.0            2.619346E-12  -2.619346E-12
         8.640005E+04   8.640005E+04  -8.640005E+04  -8.640005E+04                  8.640005E+04  -8.640005E+04
 102     8.640005E+04   8.640005E+04  -8.640005E+04  -8.640005E+04   0.0            8.640005E+04  -8.640005E+04
         1.094511E+05   1.094511E+05  -1.094511E+05  -1.094511E+05                  1.094511E+05  -1.094511E+05
 103     1.094511E+05   1.094511E+05  -1.094511E+05  -1.094511E+05  -3.429099E-11   1.094511E+05  -1.094511E+05
         1.325021E+05   1.325021E+05  -1.325021E+05  -1.325021E+05                  1.325021E+05  -1.325021E+05
 104     1.325021E+05   1.325021E+05  -1.325021E+05  -1.325021E+05  -2.432913E-11   1.325021E+05  -1.325021E+05
         2.676242E+05   2.676242E+05  -2.676242E+05  -2.676242E+05                  2.676242E+05  -2.676242E+05
 110    -1.793286E+05  -1.793286E+05   1.793286E+05   1.793286E+05  -2.503862E-14   1.793286E+05  -1.793286E+05
        -1.107762E+05  -1.107762E+05   1.107762E+05   1.107762E+05                  1.107762E+05  -1.107762E+05
 120    -9.501644E+04  -9.501644E+04   9.501644E+04   9.501644E+04  -1.251928E-14   9.501644E+04  -9.501644E+04
        -1.344295E+04  -1.344295E+04   1.344295E+04   1.344295E+04                  1.344295E+04  -1.344295E+04
 210    -1.793286E+05  -1.793286E+05   1.793286E+05   1.793286E+05  -4.460681E-12   1.793286E+05  -1.793286E+05
        -1.107762E+05  -1.107762E+05   1.107762E+05   1.107762E+05                  1.107762E+05  -1.107762E+05
 220    -9.501642E+04  -9.501642E+04   9.501642E+04   9.501642E+04   1.219428E-14   9.501642E+04  -9.501642E+04
        -1.344294E+04  -1.344294E+04   1.344294E+04   1.344294E+04                  1.344294E+04  -1.344294E+04
 310     6.873841E+02   6.873843E+02  -6.873843E+02  -6.873841E+02  -5.773503E+01   6.296493E+02  -7.451194E+02
        -1.440002E+02  -1.440000E+02   1.440000E+02   1.440002E+02                  8.626512E+01  -2.017352E+02
 FULL-SPAN MODEL                                                                                    SUBCASE 2

                                S T R E S S E S   I N   B A R   E L E M E N T S        ( C B A R )

  ELEMENT        SA1            SA2            SA3            SA4           AXIAL          SA-MAX         SA-MIN     M.S.-T
    ID.          SB1            SB2            SB3            SB4           STRESS         SB-MAX         SB-MIN     M.S.-C
 101     2.103629E-29  -2.103629E-29   2.103629E-29  -2.103629E-29   0.0            2.103629E-29  -2.103629E-29
         4.147203E+05   4.147203E+05  -4.147203E+05  -4.147203E+05                  4.147203E+05  -4.147203E+05
 102     4.147203E+05   4.147203E+05  -4.147203E+05  -4.147203E+05   0.0            4.147203E+05  -4.147203E+05
         5.218837E+05   5.218837E+05  -5.218837E+05  -5.218837E+05                  5.218837E+05  -5.218837E+05
 103     5.218837E+05   5.218837E+05  -5.218837E+05  -5.218837E+05  -1.735284E-10   5.218837E+05  -5.218837E+05
         6.290471E+05   6.290471E+05  -6.290471E+05  -6.290471E+05                  6.290471E+05  -6.290471E+05
 104     6.290472E+05   6.290472E+05  -6.290472E+05  -6.290472E+05  -1.344338E-10   6.290472E+05  -6.290472E+05
         1.288033E+06   1.253047E+06  -1.253047E+06  -1.288033E+06                  1.288033E+06  -1.288033E+06
 110    -1.422708E+06  -1.422708E+06   1.422708E+06   1.422708E+06   2.425319E-12   1.422708E+06  -1.422708E+06
        -1.065322E+06  -1.065322E+06   1.065322E+06   1.065322E+06                  1.065322E+06  -1.065322E+06
 120    -8.305978E+05  -8.305978E+05   8.305978E+05   8.305978E+05  -6.063298E-13   8.305978E+05  -8.305978E+05
        -5.265484E+05  -5.265484E+05   5.265484E+05   5.265484E+05                  5.265484E+05  -5.265484E+05
 210    -2.835362E+05  -2.835362E+05   2.835362E+05   2.835362E+05  -5.214436E-11   2.835362E+05  -2.835362E+05
         1.325060E+04   1.325060E+04  -1.325060E+04  -1.325060E+04                  1.325060E+04  -1.325060E+04
 220    -7.149380E+04  -7.149380E+04   7.149380E+04   7.149380E+04   6.063298E-13   7.149380E+04  -7.149380E+04
         4.004497E+05   4.004497E+05  -4.004497E+05  -4.004497E+05                  4.004497E+05  -4.004497E+05
 310    -1.622237E+04   2.282126E+04  -2.282126E+04   1.622237E+04  -2.771282E+02   2.254413E+04  -2.309839E+04
         1.106389E+04  -1.244629E+04   1.244629E+04  -1.106389E+04                  1.216917E+04  -1.272342E+04
```

Listing 7-21 Output for FSW Airplane in Unsymmetric Maneuvers (Continued)

```
 FULL-SPAN MODEL                                                                                        SUBCASE 3

                           S T R E S S E S   I N   B A R   E L E M E N T S        ( C B A R )

 ELEMENT        SA1            SA2            SA3            SA4           AXIAL          SA-MAX         SA-MIN      M.S.-T
   ID.          SB1            SB2            SB3            SB4           STRESS         SB-MAX         SB-MIN      M.S.-C
101     2.095477E-11   2.095477E-11  -2.095477E-11  -2.095477E-11   0.0             2.095477E-11  -2.095477E-11
        4.147203E+05   4.147203E+05  -4.147203E+05  -4.147203E+05                   4.147203E+05  -4.147203E+05
102     4.147203E+05   4.147203E+05  -4.147203E+05  -4.147203E+05   0.0             4.147203E+05  -4.147203E+05
        5.218837E+05   5.218837E+05  -5.218837E+05  -5.218837E+05                   5.218837E+05  -5.218837E+05
103     5.218837E+05   5.218837E+05  -5.218837E+05  -5.218837E+05  -1.654474E-10    5.218837E+05  -5.218837E+05
        6.290471E+05   6.290471E+05  -6.290471E+05  -6.290471E+05                   6.290471E+05  -6.290471E+05
104     6.290471E+05   6.290471E+05  -6.290471E+05  -6.290471E+05  -1.753407E-10    6.290471E+05  -6.290471E+05
        1.273732E+06   1.267348E+06  -1.267348E+06  -1.273732E+06                   1.273732E+06  -1.273732E+06
110    -1.112693E+06  -1.112693E+06   1.112693E+06   1.112693E+06   2.895225E-11    1.112693E+06  -1.112693E+06
       -8.013576E+05  -8.013576E+05   8.013576E+05   8.013576E+05                   8.013576E+05  -8.013576E+05
120    -7.028874E+05  -7.028874E+05   7.028874E+05   7.028874E+05   1.432454E-11    7.028874E+05  -7.028874E+05
       -2.918832E+05  -2.918832E+05   2.918832E+05   2.918832E+05                   2.918832E+05  -2.918832E+05
210    -5.935506E+05  -5.935506E+05   5.935506E+05   5.935506E+05  -8.700832E-11    5.935506E+05  -5.935506E+05
       -2.507142E+05  -2.507142E+05   2.507142E+05   2.507142E+05                   2.507142E+05  -2.507142E+05
220    -1.992042E+05  -1.992042E+05   1.992042E+05   1.992042E+05  -1.424875E-11    1.992042E+05  -1.992042E+05
        1.657846E+05   1.657846E+05  -1.657846E+05  -1.657846E+05                   1.657846E+05  -1.657846E+05
310     8.349175E+03  -1.750286E+03   1.750286E+03  -8.349175E+03  -2.771282E+02    8.072047E+03  -8.626303E+03
       -1.416773E+03   3.437187E+01  -3.437187E+01   1.416773E+03                   1.139645E+03  -1.693901E+03
FULL-SPAN MODEL                                                                                        SUBCASE 4

                           S T R E S S E S   I N   B A R   E L E M E N T S        ( C B A R )

 ELEMENT        SA1            SA2            SA3            SA4           AXIAL          SA-MAX         SA-MIN      M.S.-T
   ID.          SB1            SB2            SB3            SB4           STRESS         SB-MAX         SB-MIN      M.S.-C
101     0.0            0.0            0.0            0.0            0.0             0.0            0.0
        1.975245E+06   1.016282E+06  -1.016282E+06  -1.975245E+06                   1.975245E+06  -1.975245E+06
102     1.975245E+06   1.016282E+06  -1.016282E+06  -1.975245E+06   0.0             1.975245E+06  -1.975245E+06
        2.128365E+06   7.385705E+05  -7.385705E+05  -2.128365E+06                   2.128365E+06  -2.128365E+06
103     2.128365E+06   7.385705E+05  -7.385705E+05  -2.128365E+06  -7.210429E+01    2.128293E+06  -2.128437E+06
        2.281486E+06   4.608593E+05  -4.608593E+05  -2.281486E+06                   2.281414E+06  -2.281558E+06
104     2.281486E+06   4.608593E+05  -4.608593E+05  -2.281486E+06  -7.210429E+01    2.281414E+06  -2.281558E+06
        2.934946E+06   1.422994E+06  -1.422994E+06  -2.934946E+06                   2.934874E+06  -2.935018E+06
110    -1.998345E+06  -1.848014E+06   1.848014E+06   1.998345E+06  -1.245352E+04    1.985891E+06  -2.010798E+06
       -1.364391E+06  -1.238510E+06   1.238510E+06   1.364391E+06                   1.351937E+06  -1.376844E+06
120    -1.216715E+06  -1.086449E+06   1.086449E+06   1.216715E+06  -6.226760E+03    1.210488E+06  -1.222942E+06
       -1.352213E+05  -1.350319E+05   1.350319E+05   1.352213E+05                   1.289945E+05  -1.414480E+05
210    -8.496216E+05  -6.992906E+05   6.992906E+05   8.496216E+05   1.245352E+04    8.620751E+05  -8.371681E+05
       -7.347380E+05  -6.088568E+05   6.088568E+05   7.347380E+05                   7.471915E+05  -7.222845E+05
220    -5.793543E+05  -4.490888E+05   4.490888E+05   5.793543E+05   6.226760E+03    5.855811E+05  -5.731276E+05
       -1.150195E+05  -1.148301E+05   1.148301E+05   1.150195E+05                   1.212463E+05  -1.087928E+05
310     6.831474E+05  -6.953304E+05   6.953304E+05  -6.831474E+05  -1.705788E+01    6.953133E+05  -6.953474E+05
        9.646771E+04  -9.806677E+04   9.806677E+04  -9.646771E+04                   9.804972E+04  -9.808383E+04
FULL-SPAN MODEL                                                                                        SUBCASE 5

                           S T R E S S E S   I N   B A R   E L E M E N T S        ( C B A R )

 ELEMENT        SA1            SA2            SA3            SA4           AXIAL          SA-MAX         SA-MIN      M.S.-T
   ID.          SB1            SB2            SB3            SB4           STRESS         SB-MAX         SB-MIN      M.S.-C
101     1.047739E-11   1.047739E-11  -1.047739E-11  -1.047739E-11   0.0             1.047739E-11  -1.047739E-11
        1.656289E+05   1.656289E+05  -1.656289E+05  -1.656289E+05                   1.656289E+05  -1.656289E+05
102     1.656289E+05   1.656289E+05  -1.656289E+05  -1.656289E+05   0.0             1.656289E+05  -1.656289E+05
        2.085390E+05   2.085390E+05  -2.085390E+05  -2.085390E+05                   2.085390E+05  -2.085390E+05
103     2.085390E+05   2.085390E+05  -2.085390E+05  -2.085390E+05  -6.719971E-11    2.085390E+05  -2.085390E+05
        2.514492E+05   2.514492E+05  -2.514492E+05  -2.514492E+05                   2.514492E+05  -2.514492E+05
104     2.514492E+05   2.514492E+05  -2.514492E+05  -2.514492E+05  -4.013282E-11    2.514492E+05  -2.514492E+05
        5.078372E+05   5.079088E+05  -5.079088E+05  -5.078372E+05                   5.079088E+05  -5.079088E+05
110    -3.409051E+05  -3.409051E+05   3.409051E+05   3.409051E+05  -4.973799E-14    3.409051E+05  -3.409051E+05
       -2.102125E+05  -2.102125E+05   2.102125E+05   2.102125E+05                   2.102125E+05  -2.102125E+05
120    -1.802658E+05  -1.802658E+05   1.802658E+05   1.802658E+05  -2.368476E-14    1.802658E+05  -1.802658E+05
       -2.516882E+04  -2.516882E+04   2.516882E+04   2.516882E+04                   2.516882E+04  -2.516882E+04
210    -3.410176E+05  -3.410176E+05   3.410176E+05   3.410176E+05  -1.697250E-11    3.410176E+05  -3.410176E+05
       -2.103239E+05  -2.103239E+05   2.103239E+05   2.103239E+05                   2.103239E+05  -2.103239E+05
220    -1.803301E+05  -1.803301E+05   1.803301E+05   1.803301E+05   2.131628E-14    1.803301E+05  -1.803301E+05
       -2.528661E+04  -2.528661E+04   2.528661E+04   2.528661E+04                   2.528661E+04  -2.528661E+04
310     1.327850E+03   1.307581E+03  -1.307581E+03  -1.327850E+03  -1.106781E+02    1.217172E+03  -1.438528E+03
       -2.901609E+02  -2.619355E+02   2.619355E+02   2.901609E+02                   1.794828E+02  -4.008390E+02
```

FSW Airplane with Bodies

This example is a modification of the full-span Example HA144E to include a fuselage, under-wing pylon-mounted stores as well as wing incidence and outboard dihedral. Three views are shown in Figure 7-13. The primary purpose of this example is to illustrate the inclusion of body interference in a quasi-static problem.

However, a tapered fuselage is also chosen to demonstrate a modeling feature of the Giesing Method of Images that requires moving the canard vertically (in this example) from its physical location so that its root intersects the interference tube while maintaining the same span and spanwise location. The DMI input for wing incidence is affected by the dihedral, and this feature is also illustrated. Only the sea-level flight condition at $m = 0.9$ is considered since the example is only intended to illustrate the data input.

The Configuration

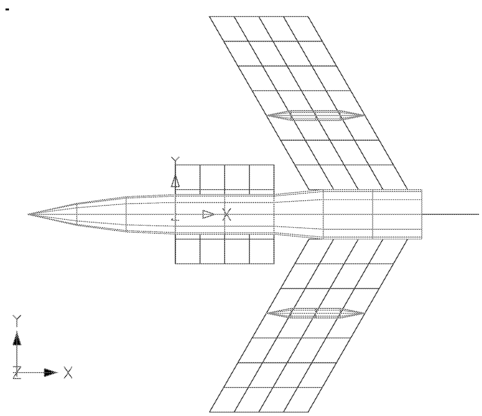
The fuselage is assumed to be 40.0 ft long with the nose 5.0 ft forward of GRID 97 and the aft end 5.0 ft behind GRID 100. Its assumed circular cross section has a diameter of 5.0 ft at the root of the wing and tapers in diameter to 4.0 ft at the root of the canard; a parabolic ogive extends forward of the canard to the nose. The wing and canard spans are maintained at 40.0 and 10.0 ft, respectively, as before. The wing stores are mounted on pylons at the midspan of each wing. The pylons have a chord of 5.0 ft and extend below the wing 1.0 ft and are centrally aligned on the wing chord. Each store is 10.0 ft long with a diameter of 1.0 ft in the region of the pylon with a pointed nose and an aft end. The stores are centrally aligned along the pylons. The wings are assumed to have an incidence of 0.1 deg relative to the fuselage centerline and to have a dihedral break at the pylons such that the wing tip chord is 2.0 ft above the inboard wing plane.

Structural models for the canard, pylons, and stores are added. An elastic axis (CBAR) representation of the canard is assumed from the fuselage centerline (GRID 90) to the canard tips along the canard midchord (50%) line. A vertical elastic axis is assumed for the pylons between the wing elastic axis and the store elastic axis, which is assumed along the store centerline. The same stiffness properties are assumed for the canard, pylon, and store elastic axes as for the wing.

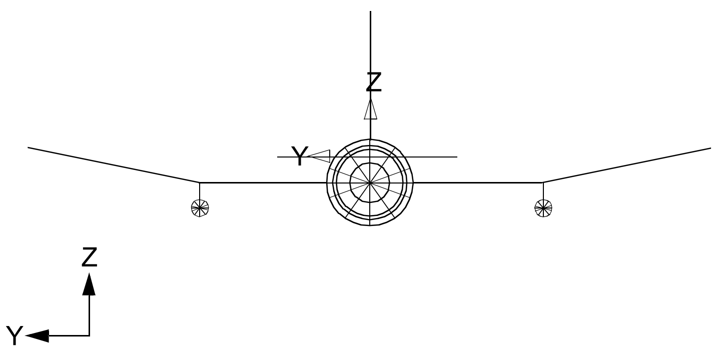
Additional Structural Model

The additions to the structural model begin with grid points. First, the wings have been modified to introduce the dihedral: GRIDs 115 and 215 are introduced on the right and left wing elastic axes, respectively, to define the pylon station and dihedral break. Next, the points on the canard elastic axis are GRIDs 88, 89, 91, 92, 890, and 910. GRIDs 88 and 92 are at the left and right canard tips, respectively. GRIDS 89 and 91 are at the left and right sides of the fuselage, respectively. GRIDs 890 and 910 are also at the sides of the fuselage, coincident with GRIDs 89 and 91, respectively, and are introduced by the requirements of the aerodynamic Method of Images, as is discussed below. The canard hinge line is now assumed to be located along its elastic axis (in previous examples with this configuration, the hinge line was assumed to be located at the canard quarter-chord). GRIDs 150 and 151 locate the right pylon/store: 150 is forward on the store elastic axis, and 151 is aft on the store elastic axis and also at the bottom of the pylon elastic axis. The corresponding GRIDs on the left pylon/store are 250 and 251.

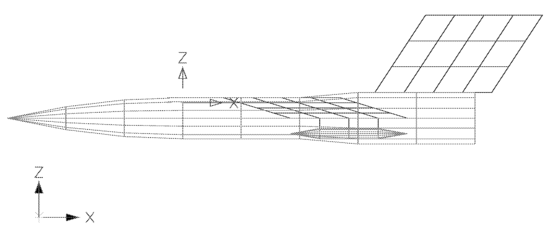
Main Index



(a) Plan View



(b) Front View



(c) Side View

Figure 7-13 Three Views of the Aerodynamic Model for the FSW Airplane with Fuselage and Stores

The wing elastic axes are represented by two BAR elements on each side. On the right wing, CBAR 115 connects GRIDs 110 and 115, and CBAR 120 connects GRIDs 115 and 120. On the left wing, CBAR 215 connects GRIDs 210 and 215, and CBAR 220 connects GRIDs 215 and 220. The canard structural elements also consist of BARs: CBAR 89 between GRIDs 88 and 89, CBAR 90 between GRIDs 890 and 90, CBAR 91 between GRIDs 90 and 910, and CBAR 92 between GRIDs 91 and 92.

The right pylon structural element is CBAR 151 between GRIDs 115 and 150, and the right store structural element is CBAR 150 between GRIDs 150 and 151. The corresponding left pylon/store elements are CBARs 251 and 250. All of these new elements refer to the property and material entries for the wing, PBAR 101 and MAT1 1, for their stiffnesses. No additional weights are considered in the additions of the canard structure and the pylons and stores.

Aerodynamic Model

The wings are divided into two panels on each side, having the same size boxes as before, with the fuselage replacing the inboard strips of boxes on each side, and also with an outboard dihedral angle (11.31 deg). The right inboard wing is specified on lifting surface entry CAERO1 1104, which refers to PAERO1 1000 for the identification of any associated bodies. PAERO1 1000 now refers to the fuselage CAERO2 4000, the right store CAERO2 4510, and the left store, CAERO2 4610. CAERO1 1104 then specifies 3 equal span strips and 4 equal chord boxes in the first interference group. The planform geometry on the continuation entry begins with the leading edge location at the root of the wing (which is now displaced by the radius of the fuselage in the wing region, 2.5 ft), the root chord length, and the leading edge location at the dihedral break and its chord length.

The right outboard wing is specified on entry CAERO1 1116, which associates the panel with the three bodies using the PAERO1 entry and divides the panel equally into four spanwise strips and four chordwise boxes in the first interference group. The continuation entry provides the leading edge location and chord length at the dihedral break and then the leading edge location and chord length at the tip.

Two splines are now needed on each wing because of the dihedral break. On the right inboard wing, SPLINE2 1602 with its axis CORD2R 2 as before, but now with grid points designed by SETG 1101. On the right outboard wing, the spline is prescribed by SPLINE2 1603 with a new axis CORD2R 3 and grid points designated by SETG 1102 prescribe the spline. CAERO1s 2100 and 2116 provide similar data for the left wing, arbitrarily numbering the boxes from the tip inboard, whereas the right wing box numbering scheme begins at the root and increases outboard. The left wing spline and spline axes are also similar: for the outboard wing, SPLINE2 2601 with CORD2R 30 and SETG 2102, and for the inboard wing, SPLINE2 2602 with CORD2R 20 and SETG 2101.

Pylons

The right wing pylon is specified on lifting surface entry CAERO1 3500 and is modelled as one strip with two chordwise boxes and is associated with all three bodies. Its spline is SPLINE2 4520 with axis CORD2R 450 and structural connection to grid points SETG 4521. The left wing pylon is similar to the lifting surface entry CAERO1 3600; its spline is SPLINE2 4620 with axis CORD2R 460 and structural connection to points SETG 4621.

Main Index

Canard

The right side of the canard is specified on entry CAERO1 1000. It associates the panel with the three bodies, specifies the right side geometry in the Cartesian coordinate system CORD2R 900 (for reasons to be discussed below regarding the requirements of the Method of Images), divides the span unequally into two strips with four chordwise boxes via AEFACT 1000 in order to align the trailing vortices with the wing in the same interference group. The geometry on the continuation entry begins with the leading edge location at the root of the canard (displaced here by the radius of the fuselage in the canard region, 2.0 ft), the root chord length, and then the leading edge location of the tip and the tip chord. The right canard is now interconnected using the new SPLINE2 1502 with its elastic axis along CORD2R 90 to the structural grid points on both sides, SET1 1000. The hinge line is also aligned with the elastic axis in this modification to Example HA144E. CAERO1 2000 and AEFACT 2000 provide similar data for the left side of the canard but with the box numbering scheme beginning at the tip leading edge. The associated spline is SPLINE2 2501 with the same axis CORD2R 90 and structural connection SET1 1000.

Fin

The fin is again specified on entry CAERO1 3100 but with only three strips because of the presence of the fuselage and modified geometry on the continuation entry for the leading edge location at the fuselage junction.

Fuselage

The fuselage aerodynamic properties are given on entry CAERO2 4000:

- In the PID field, the reference is to the entry PAERO2 4020, which specifies additional data for the fuselage.
- The CP field refers to the coordinate system for the fuselage geometry; in this case, it is blank and thus refers to the basic system.
- The NSB field specifies eight equal length divisions of the fuselage.
- Because of the NSB field specification, the LSB field is not needed.
- The NINT field also specifies eight equal divisions of the interference tube.
- The LINT field, like the LSB field, is again not needed.
- The IGID field specifies the same interference group as the other aerodynamic components.

The continuation entry contains the coordinates of the fuselage nose and its length.

- The additional fuselage data on entry PAERO2 4020 include:
- The ORIENT field, which is the body orientation, (in this case ZY) specifies that the fuselage can move both vertically and laterally.
- The WIDTH field, which is actually the semiwidth or radius of 2.5 ft in this case since the cross section is circular. This is the maximum width of the fuselage at the root of the wing, and this also determines the width of the interference tube.
- The AR field, is the aspect ratio (the ratio of the height to the width) of the possibly elliptical cross section; in this case, AR = 1.0 specifies a circular section.

Main Index

- The LRSB field, refers to the entry AEFACT 4015, which lists the half-widths at the nine end points of the eight slender body elements.
- The LRIB field is the reference to a list of slender body half-widths at the end points of the eight interference elements but is left blank in accordance with the recommendation in Internal Aerodynamic Theories, 15.
- The LTH1 field refers to the entry AEFACT 4018, which lists the angular positions (the q_1 array) around the periphery of the interference tube for averaging the interfering flow from the lifting surfaces and other slender bodies; in this case, four sampling points are selected beginning at 45 deg and every 90 deg beyond.
- The LTH2 field could refer to a alternate list of angular positions, as discussed in Internal Aerodynamic Theories, 15 (the θ_2 array), but is not used here.

The continuation entry lists pairs of first and last interference elements that use the array; in this case, all eight interference elements use the same array. The fuselage spline is SPLINE2 4000 and is connected to structural grid points SET1 4001. Note that the linear spline used for a body does not require the specification of a coordinate system for the spline axis along the body.

The right store aerodynamic properties are entered on CAERO2 4510. The third field of the entry refers to PAERO2 4520 for additional body data. The fifth and sixth fields specify four equal length divisions of both the body and its interference tube. The continuation locates the store nose below the wing leading edge and gives its length as 10.0 ft. The additional properties on PAERO2 4520 include the ZY degrees of freedom, the reference width of 0.5 ft, and AR = 1.0 for the circular cross section. LRSB refers to AEFACT 4515 for the list of store half-widths at the five end points of the four slender body elements, and LTH1 refers to the same q_1-array used for the fuselage, AEFACT 4018. The continuation entry specifies that the four interference elements will use the single array. The right store spline is SPLINE2 4525 and is interconnected to grids SET1 4525. The left store CAERO2 4610 entry is similar except for its nose location and uses the additional data for the right store on entry PAERO2 4520. Its spline is SPLINE2 4625 with connections to SET1 4625.

Wing Incidence and Dihedral

The remaining new configuration data are the DMI entries to specify the wing incidence of $0.1 \text{ degrees} = 0.0017453 \text{ radians}$. Because of the dihedral angle of $\Gamma = \tan^{-1}0.2 = 11.31 \text{ deg}$, the outboard wing panels have less incidence than the inboard panels by a factor of cos G, and the outboard value becomes 0.0017114 rad. The DMI name for incidence, twist, and camber is W2GJ. Since the incidence is constant for a number of boxes in this example, the DMI input can use the convenience of the THRU data input option, but it requires the j-set numbering of the aerodynamic boxes in the sequence from the right wing root to the left wing root (see Internal Aerodynamic Theories). The numbering begins with the lowest numbered CAERO1 identification number. The right side canard (CAERO1 1000) has eight boxes; thus, the first inboard wing (CAERO1 1104) box is No. 9; the last box on the right inboard wing is No. 20 since there are 12 boxes on the inboard wing. There are 16 boxes on the right outboard wing (CAERO1 1116), and their numbers range from No. 21 to No. 36. The left canard (CAERO1 2000) intervenes in the sequence with its eight boxes; therefore, the next 16 wing boxes begin with No. 45 at the outboard left wing (CAERO1 2100) tip and range to No. 60 at the dihedral break. The twelve inboard left wing (CAERO1 2116) boxes range from No. 61 to No. 72. The remaining lifting surfaces are beyond the range of concern to DMI W2GJ (and the bodies must have even higher numbers). However, it is necessary to specify the correct number of rows for the matrix which is the M field (152 in this case, see Aerodynamic Modeling) on the parent DMI entry.

Interference

The final modeling task is to satisfy the requirements of Giesing's Method of Images [Giesing, Kalman, and Rodden (1972a, Section 2.5.8) [Reference 19]]. This example has a tapered fuselage, and is narrower forward in the region of the canard and wider aft at the root of the wing. The idealization selected chose the aft fuselage cross section as the reference for the interference tube which, in this example, is the circular cross section of the aft fuselage slender body. This idealization places its emphasis on modeling the aft fuselage interference effects, rather than on the effects of the canard. (In order to emphasize the effects of the canard, the interference tube would have chosen the fuselage cross section in the canard region as its reference.)

With the larger diameter interference tube, the physical model has the canard root inside the interference tube. If the physical model were used for the data input, numerical singularities could arise because the external singularities of the lifting surface could be inside with the images. This situation violates the requirements of the Method of Images, which permits only a system of images inside the interference tube (and the line of axial doublets along the body centerline). The physical model of the lifting surfaces must be modified to maintain all parts of lifting surfaces outside of all interference tubes. A further judgment is required regarding which aeroelastic characteristics to emphasize: longitudinal or lateral-directional. This example emphasizes the longitudinal characteristics; therefore, the results will be more comparable to Example HA144A (and HA144E).

The canard is raised vertically until its root intersects the interference tube at a height of 1.5 ft (recall that the fuselage has a radius of 2.0 ft at the root of the canard and the interference tube has a diameter of 2.5 ft). A new coordinate system, CORD2R 900, is introduced and the canard geometry is specified in this system. This coordinate system has its origin at the fuselage centerline, the extension of the canard leading edge, and an elevation of 1.5 ft relative to the basic coordinate system. This coordinate system moves the canard physically so that no part of it is within the interference tube and satisfies the requirements of the Method of Images.

However, there is now a structural discontinuity that can be resolved by the use of multipoint constraints (MPCs). Four GRIDs are introduced at the intersections of the canard elastic axis and the sides of the fuselage; these are GRIDs 91 and 910 on the right side and GRIDs 89 and 890 on the left side. The right canard elastic axis CBAR 91 extends from the fuselage centerline GRID 90 to the side of the fuselage GRID 910 which is located in the basic coordinate system; the elastic axis continues outboard in CBAR 92 from GRIDs 91 to 92 located in CORD2R 900. GRIDs 91 and 910 are in identical locations but in different coordinate systems. The continuity of structural loads is assured by MPC 10, which provides the identity of all six components of GRIDS 91 and 910. Similarly, the left elastic axis, CBAR 90, connects GRIDs 90 and 890 within the fuselage in the basic coordinates, and CBAR 89 connects GRIDs 88 and 89 on the canard in CORD2R 900. Again, GRIDs 89 and 890 are identically located but in different coordinate systems, and MPC 10 also guarantees structural continuity by connecting all six components of GRIDs 89 and 890.

Trim Condition

Only the level flight condition at sea level (Mach number $m = 0.9$ and dynamic pressure $\bar{q} = 1200 \text{ psf}$) is considered in the present example (corresponding to Subcase 1 of previous Example HA144E) since this example is primarily intended to illustrate the inclusion of slender bodies in a quasi-static aeroelastic analysis. The effects of the pylons, bodies, and dihedral on the stability derivatives may be of interest, and a limited comparison with the longitudinal values of Example HA144E is shown in Table 7-7. The trim angle of attack and canard rotation are different from HA144E, not only because of the bodies but also because of the addition of incidence and dihedral. The aerodynamic and structural loads are not discussed here but are shown in Listing 7-24 as information for the user.

Case Control Commands

The Case Control commands and the Executive Control statements are the same as in ExampleHA144E with the exception of the titles. The input data file echo for this example is shown below in Listing 7-22 followed by the sorted Bulk Data entries in Listing 7-23 and the output in Listing 7-24.

Output. The significant output data in this example relate to the addition of the slender bodies to the configuration. The stability derivatives are compared to those from Example HA144E (without the bodies) in Table 7-7, and the aerodynamic loads on the bodies which are contained at the end of the AEROSTATIC DATA RECOVERY OUTPUT TABLE in Listing 7-24. The most significant differences relate to the canard, as would be expected.

Aerodynamic Forces and Pressures

Pressures are not available for the body elements but tabulated in place of the pressures are the values of μ_I, the strengths of the acceleration potential interference doublets, and μ_s, the strengths of the acceleration potential slender element doublets. The loads on the slender elements are listed under NORMAL FORCES and MOMENTS and their components are labeled as YSB and ZSB for y-forces and z-forces, respectively. Their moments are zero because the grid point for all aerodynamic elements is at midchord and the distributed loading on a slender element has been assumed to act at this point. The eight fuselage element numbers are 4000 through 4007 and their side forces, YSB, are computed zeros because of the symmetry of the configuration and the maneuver; the vertical forces, ZSB, are all positive, upward in the aerodynamic coordinate system. The external store numbers are 4510 through 4513 on the right side, and 4610 through 4613 on the left. The side forces on both stores act away from the fuselage (the net pylon forces, LS 3500 and 3501 on the right and 3601 and 3601 on the left, also act away from the fuselage). The vertical store forces act upward on the forward three elements of each store but downward on the aft boattail elements as expected from Slender Body Theory.

Dihedral Effects

As previously noted, the Vortex-Lattice method (VLM) in MSC Nastran cannot predict all of the lateral-directional characteristics of wings. In this example, outboard dihedral was added to the wings. The dihedral effect refers to the rolling moment coefficient due to sideslip. The total dihedral effect of a wing should include the effects of geometric dihedral and its change under symmetric load factor and the effect of sweep. The first two effects can be found in MSC Nastran. The geometric dihedral is accounted for in this example. The effect of load factor can be found by a restart that adds the previously determined deflections to the planform description on the wing CAERO1 entries, and the total geometric dihedral effect at the trim load factor will be obtained. The effect of sweep on the dihedral effect is a second order effect, depending on the lift coefficient, and can be estimated by the methods of Finck and Hoak (1976) [Reference 15]. In the case of general configurations with vertical surfaces, for example, the fin and pylons in this example, MSC Nastran will also predict their additional contributions to the dihedral effect.

Table 7-7 Longitudinal Derivatives for Two Example FSW Airplanes

Derevative	Example HA144E			Example HA144F		
	Rigid Value	Restrained Value at q = 1200 psf	Unrestrained Value at q = 1200 psf	Rigid Value	Restrained Value at $\bar{q}$ = 1200 psf	Unrestrained Value at $\bar{q}$ = 1200 psf
C_{z_o}	0.0	0.0	0.0	-0.007502	-0.009902	-0.012222
C_{m_o}	0.0	0.0	0.0	-0.004899	-0.006365	-0.007934
C_{z_α}	-5.071	-6.463	-7.788	-5.040	-6.537	-7.993
C_{m_α}	-2.871	-3.667	-4.590	-2.878	-3.791	-4.777
$C_{z_{\delta_e}}$	-0.2461	-0.5430	-0.5181	-0.10379	-0.1600	-0.1445
$C_{m_{\delta_e}}$	0.5715	0.3860	0.3980	0.2340	0.1988	0.2089
C_{z_q}	-12.074	-12.856	-16.166	-11.984	-13.248	-16.837
C_{m_q}	-9.954	-10.274	-12.545	-9.633	-10.352	-12.765
$C_{z_{\ddot{z}}}$	-	0.003809	-	-	0.004104	-
$C_{m_{\ddot{z}}}$	-	0.002738	-	-	0.002821	-
$C_{z_{\ddot{\theta}}}$	-	0.01521	-	-	0.016112	-
$C_{m_{\ddot{\theta}}}$	-	0.009872	-	-	0.010478	-
α_{m_o}	-	0.0	-	-	-0.0001219	-
α_{m_α}	-	0.9269	-	-	0.9258	-
$\alpha_{m_{\delta_e}}$	-	0.006723	-	-	0.002294	-
α_{m_q}	-	-0.2121	-	-	-0.2095	-
$\alpha_{m_{\ddot{z}}}$	-	-0.0001225	-	-	-0.0001234	-
$\alpha_{m_{\ddot{\theta}}}$	-	-0.001491	-	-	-0.001489	-

Listing 7-22 Input Files for FSW Airplane with Bodies

```
  N A S T R A N   E X E C U T I V E   C O N T R O L   D E C K   E C H O
ID MSC, HA144F
$$$$$$  USERS GUIDE FOR AEROELASTIC ANALYSIS EXAMPLE HA144F       $$$$$$
$                                                                      $
$       MODEL DESCRIPTION        FULL SPAN 30 DEG FWD SWEPT WING       $
$                                WITH AILERON, CANARD AND AFT SWEPT    $
$                                VERTICAL FIN AND RUDDER.              $
$                                BAR MODEL WITH DUMBBELL MASSES.       $
$                                                                      $
$       SOLUTION                 QUASI-STEADY AEROELASTIC ANALYSIS     $
$                                USING DOUBLET-LATTICE METHOD          $
$                                AERODYNAMICS AT MACH NO. 0.9.         $
$                                                                      $
$       OUTPUT                   PLOTS OF THE STICK MODEL AND AERO     $
$                                GRID, LISTS OF RESTRAINED AND         $
$                                UNRESTRAINED SYMMETRIC AND ANTI-      $
$                                SYMMETRIC STABILITY DERIVATIVES,      $
$                                AERODYNAMIC FORCES AND PRESSURES      $
$                                PLUS STRESSES AND DEFLECTIONS FOR     $
$                                LEVEL FLIGHT AND SEVERAL UNSYM-       $
$                                METRICAL MANUEVERS.                   $
$                                                                      $
$                                                                      $
$$$$$$$$                                                        $$$$$$$$
TIME 10 $ CPU TIME IN MINUTES
SOL 144 $ STATIC AERO
CEND
```

```
    EXAMPLE HA144F: FSW WITH FUSELAGE, 3 CONTROLS & 2 STORES
PAGE     2
     UNSYMMETRIC FLIGHT CONDITIONS, DOUBLET-LATTICE AERO
    FULL-SPAN MODEL WITH DISPLACED CANARD
                               C A S E   C O N T R O L   D E C K   E C H O
          CARD
          COUNT
           1      TITLE = EXAMPLE HA144F: FSW WITH FUSELAGE, 3 CONTROLS & 2 STORES
           2      SUBTI = UNSYMMETRIC FLIGHT CONDITIONS, DOUBLET-LATTICE AERO
           3      LABEL = FULL-SPAN MODEL WITH DISPLACED CANARD
           4        ECHO    = BOTH
           5        SPC     = 1   $ SYMMETRIC CONSTRAINTS
           6        MPC     = 10  $ CANARD/FUSELAGE STRUCTURAL CONNECTIONS
           7        DISP    = ALL $ PRINT ALL DISPLACEMENTS
           8        STRESS  = ALL $ PRINT ALL STRESSES
           9        FORCE   = ALL $ PRINT ALL FORCES
          10        AEROF   = ALL $ PRINT ALL AERODYNAMIC FORCES
          11        APRES   = ALL $ PRINT ALL AERODYNAMIC PRESSURES
          12      SUBCASE 1
          13        TRIM = 1      $ HIGH SPEED LEVEL FLIGHT
          14      OUTPUT(PLOT)
          15        PLOTTER = NASTRAN
          16        SET 1 = ALL
          17        FIND SCALE, ORIGIN 1,SET 1
          18        PLOT SET 1
          19        PLOT STATIC DEFORMATION 0, ORIGIN 1, SET 1, OUTLINE
          20      BEGIN BULK
```

Listing 7-22 Input Files for FSW Airplane with Bodies (Continued)

```
    EXAMPLE HA144F: FSW WITH FUSELAGE, 3 CONTROLS & 2 STORES
PAGE    3
     UNSYMMETRIC FLIGHT CONDITIONS, DOUBLET-LATTICE AERO
    FULL-SPAN MODEL WITH DISPLACED CANARD
                                 I N P U T   B U L K   D A T A   D E C K   E C H O

           .  1  ..  2  ..  3  ..  4  ..  5  ..  6  ..  7  ..  8  ..  9  ..  10  .
                $*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
                $                                                                      $
                $        THE ANNOTATIONS IN THIS INPUT DECK ARE INTENDED TO            $
                $        EXPLAIN THE DATA ON THE CARD IMAGES FOR THIS SPECIFIC         $
                $        EXAMPLE WITHOUT REFERENCE TO THE VARIOUS MANUALS WHERE        $
                $        MORE GENERAL DESCRIPTIONS WILL BE FOUND.                      $
                $                                                                      $
                $*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
                $                                                                      $
                $                       * * * STRUCTURAL DATA * * *                    $
                $                                                                      $
                $                            (LB-FT-SEC SYSTEM)                        $
                $                                                                      $
                $                          * * GRID GEOMETRY * *                       $
                $                                                                      $
                $        GRID  90 - 100 (T3) FUSELAGE POINTS                           $
                $        GRID 110 - 122 (T3) WING POINTS                               $
                $        GRID 310 - 312 (T3) FIN POINTS                                $
                $                                                                      $
                $                            * FUSELAGE GRID *                         $
                $                                                                      $
                $        THE GRID ENTRY DEFINES THE LOCATION OF A STRUCTURAL GRID      $
                $        POINT.  LISTED ARE ITS COORDINATE SYSTEM ID, ITS LOCATION,    $
                $        THE ID OF THE COORDINATE SYSTEM IN WHICH ITS DISPLACEMENTS    $
                $        ARE DEFINED, ITS PERMANENT SINGLE-POINT CONSTRAINTS AND       $
                $        ITS ASSOCIATED SUPERELEMENT ID.                               $
                $                                                                      $
                $       ID      CP      X1      X2      X3      CD      PS      SEID
                GRID    90              15.     0.      0.
                GRID    97              0.      0.      0.
                GRID    98              10.     0.      0.
                GRID    99              20.     0.      0.
                GRID    100             30.     0.      0.
                GRID    890             15.     -2.0    0.
                GRID    910             15.     +2.0    0.
                $                                                                      $
                $                      * LEFT CANARD GRID *
                $       ID      CP      X1      X2      X3      CD      PS      SEID
                GRID    88      900     5.0     -5.0    0.0
                GRID    89      900     5.0     -2.0    0.0
                $
                $                      * RIGHT CANARD GRID *
                $
                GRID    91      900     5.0     2.0     0.0
                GRID    92      900     5.0     5.0     0.0
                $
                $                ** CANARD COORDINATE SYSTEMS **
                $
                $                 * CANARD HINGELINE AND ELASTIC AXIS *
                $
                $       CID     CS      A1      A2      A3      B1      B2      B3      +CRD
                CORD2R  90      900     5.0     0.0     0.0     5.0     0.0     15.0    +CRD90C
                $       C1      C2      C3
                +CRD90C 20.0    0.0     0.0
                $
                $         * COORDINATES AT CANARD/INTERFERENCE TUBE INTERSECTION *
                $
                $       CID     CS      A1      A2      A3      B1      B2      B3      +CRD
                CORD2R  900             10.0    0.0     1.5     10.0    0.0     15.0    +CRD900C
                $       C1      C2      C3
                +CRD900C20.0    0.0     1.5
                $
                $                        * RIGHT WING GRID *                           $
                $                                                                      $
                $       ID      CP      X1      X2      X3      CD      PS      SEID
                GRID    111             24.61325 +5.    0.
                GRID    110             27.11325 +5.    0.
                GRID    112             29.61325 +5.    0.
                GRID    115             24.22650+10.    0.
                GRID    121             18.83975+15.    1.
                GRID    120             21.33975+15.    1.
                GRID    122             23.83975+15.    1.
                $                                                                      $
```

Listing 7-22 Input Files for FSW Airplane with Bodies (Continued)

```
$                        * RIGHT STORE GRID *
$
GRID    150             19.22650+10.    -1.5
GRID    151             24.22650+10.    -1.5
$
$                        * LEFT WING GRID *                             $
$                                                                       $
$       ID      CP      X1      X2      X3      CD      PS      SEID
GRID    211             24.61325 -5.    0.
GRID    210             27.11325 -5.    0.
GRID    212             29.61325 -5.    0.
GRID    215             24.22650-10.    0.
GRID    221             18.83975-15.    1.
GRID    220             21.33975-15.    1.
GRID    222             23.83975-15.    1.
$                                                                       $
$                        * LEFT STORE GRID *
$
GRID    250             19.22650-10.    -1.5
GRID    251             24.22650-10.    -1.5
$
$                            * FIN GRID *                               $
$                                                                       $
GRID    310             32.88675+0.     5.
GRID    311             30.38675+0.     5.
GRID    312             35.38675+0.     5.
$                                                                       $
$               * * STRUCTURAL STIFFNESS PROPERTIES * *                 $
$                                                                       $
$                       * FUSELAGE STRUCTURE *                          $
$                                                                       $
$       THE CBAR ENTRY DEFINES A SIMPLE BEAM ELEMENT.  LISTED ARE       $
$       ITS PROPERTY ENTRY ID, THE TWO GRID POINTS JOINED BY THE        $
$       BEAM AND COMPONENTS OF A VECTOR FROM THE FIRST POINT.           $
$       THIS VECTOR DEFINES THE DIRECTION OF THE STRUCTURAL DE-         $
$       FLECTION OF THE POINT AND ITS POSITIVE SENSE.                   $
$                                                                       $
$       EID     PID     GA      GB      X1,GO   X2      X3
CBAR    101     100     97      98      0.      0.      1.
CBAR    102     100     98      90      0.      0.      1.
CBAR    100     100     90      99      0.      0.      1.
CBAR    103     100     99      100     0.      0.      1.
$                                                                       $
$       THE PBAR ENTRY DEFINES GEOMETRIC PROPERTIES OF THE BEAM.        $
$       LISTED ARE ITS ASSOCIATED MATERIAL ENTRY ID, ITS CROSS SEC-     $
$       TIONAL AREA, AREA MOMENTS OF INERTIA, TORSIONAL MOMENT          $
$       OF INERTIA AND NON-STRUCTURAL MASS PER UNIT AREA.  THE          $
$       OPTIONAL CONTINUATION ENTRY CONTAINS STRESS RECOVERY            $
$       COEFFICIENTS, that is, Y,Z COORDINATES WHERE STRESSES ARE       $
$       TO BE COMPUTED.  K1 AND K2 ARE AREA FACTORS FOR SHEAR           $
$       STIFFNESS (DEFAULT IS BLANK; THEN SHEAR STIFFNESS IS            $
$       INFINITE, that is, SHEAR FLEXIBILITY IS ZERO.  I12 IS THE       $
$       AREA PRODUCT OF INERTIA.                                        $
$                                                                       $
$       PID     MID     A       I1      I2      J       NSM
PBAR    100     1       4.0     .347222 .30     1.0                     +PB1F
$       C1      C2      D1      D2      E1      E2      F1      F2
+PB1F   1.0     1.0     1.0     -1.0    -1.0    1.0     -1.0    -1.0    +PB2F
$       K1      K2      I12
+PB2F                   0.0
$                                                                       $
$                        * CANARD STRUCTURE *
$       EID     PID     GA      GB      X1,G0   X2      X3
CBAR    89      101     88      89      0.      0.      1.
CBAR    90      101     890     90      0.      0.      1.
CBAR    91      101     90      910     0.      0.      1.
CBAR    92      101     91      92      0.      0.      1.
$
$           * LEFT CANARD/FUSELAGE STRUCTURAL CONNECTION *
$
MPC     10      89      1       1.0     890     1       -1.0
MPC     10      89      2       1.0     890     2       -1.0
MPC     10      89      3       1.0     890     3       -1.0
MPC     10      89      4       1.0     890     4       -1.0
MPC     10      89      5       1.0     890     5       -1.0
MPC     10      89      6       1.0     890     6       -1.0
$
$           * RIGHT CANARD/FUSELAGE STRUCTURAL CONNECTION *
$
MPC     10      91      1       1.0     910     1       -1.0
MPC     10      91      2       1.0     910     2       -1.0
MPC     10      91      3       1.0     910     3       -1.0
MPC     10      91      4       1.0     910     4       -1.0
MPC     10      91      5       1.0     910     5       -1.0
MPC     10      91      6       1.0     910     6       -1.0
$
```

Listing 7-22 Input Files for FSW Airplane with Bodies (Continued)

```
$                        * RIGHT WING STRUCTURE *                       $
$                                                                       $
$       EID     PID     GA      GB      X1,GO   X2      X3
CBAR    110     101     100     110     0.      0.      1.
CBAR    115     101     110     115     0.      0.      1.
CBAR    120     101     115     120     0.      0.      1.
$                                                                       $
$       THE RBAR ENTRY DEFINES A RIGID BAR.  LISTED ARE THE GRID        $
$       POINTS AT EACH END AND THE DEPENDENT AND INDEPENDENT DOFS       $
$       AT EACH END.  THE NUMBER OF INDEPENDENT DOFS AT THE TWO         $
$       ENDS MUST EQUAL SIX.  BY DEFAULT THOSE NOT DECLARED INDE-       $
$        PENDENT ARE MADE DEPENDENT.                                    $
$                                                                       $
$       EID     GA      GB      CNA     CNB     CMA     CMB
RBAR    111     110     111     123456
RBAR    112     110     112     123456
RBAR    121     120     121     123456
RBAR    122     120     122     123456
$                                                                       $
$       PID     MID     A       I1      I2      J       NSM
PBAR    101     1       1.5     0.173611+2.0    0.462963                +PB1W
$       C1      C2      D1      D2      E1      E2      F1      F2
+PB1W   0.5     3.0     0.5     -3.0    -0.5    3.0     -0.5    -3.0    +PB2W
$       K1      K2      I12
+PB2W                   0.0
$                                                                       $
$                        * LEFT WING STRUCTURE *                        $
$                                                                       $
$       EID     PID     GA      GB      X1,GO   X2      X3
CBAR    210     101     100     210     0.      0.      1.
CBAR    215     101     210     215     0.      0.      1.
CBAR    220     101     215     220     0.      0.      1.
$
RBAR    211     210     211     123456
RBAR    212     210     212     123456
RBAR    221     220     221     123456
RBAR    222     220     222     123456
$                                                                       $
$                   * RIGHT  PYLON/STORE STRUCTURE *                     $
$                                                                       $
$       EID     PID     GA      GB      X1,GO   X2      X3
CBAR    150     101     150     151     0.      0.      1.
CBAR    151     101     151     115     1.      0.      0.
$
$                   * LEFT PYLON/STORE STRUCTURE *                      $
$                                                                       $
$       EID     PID     GA      GB      X1,GO   X2      X3
CBAR    250     101     250     251     0.      0.      1.
CBAR    251     101     251     215     1.      0.      0.
$
$                           * FIN STRUCTURE *                           $
$                                                                       $
CBAR    310     101     100     310     0.      0.      1.
$                                                                       $
RBAR    311     310     311     123456
RBAR    312     310     312     123456
$                                                                       $
$       THE MAT1 ENTRY DEFINES THE MATERIAL PROPERTIES.  LISTED         $
$       ARE ITS ID, ITS ELASTIC MODULUS, SHEAR MODULUS, POISSONS        $
$       RATIO, MASS DENSITY, TEMPERATURE EXPANSION COEFFICIENT,         $
$       REFERENCE TEMPERATURE AND A STRUCTURAL DAMPING COEFFICIENT.     $
$                                                                       $
$       MID     E       G       NU      RHO     A       TREF    GE
MAT1    1       1.44+9  5.40+8
$                                                                       $
$                 * * MASS AND INERTIA PROPERTIES * *                   $
$                                                                       $
$                         * FUSELAGE MASSES *                           $
$                                                                       $
$       THE CONM2 ENTRY DEFINES A CONCENTRATED MASS.  LISTED ARE        $
$       ITS ID, GRID LOCATION, COORDINATE SYSTEM TO LOCATE THE          $
$       CENTER OF GRAVITY, THE MASS VALUE AND THE LOCATION OF           $
$       THE CENTER OF GRAVITY RELATIVE TO THE GRID LOCATION.            $
$                                                                       $
$       EID     G       CID     M       X1      X2      X3
CONM2   97      97      0       3000.0
CONM2   98      98      0       3000.0
CONM2   99      99      0       3000.0
CONM2   100     100     0       3000.0
$                                                                       $
$                        * RIGHT WING MASSES *                          $
$                                                                       $
CONM2   111     111     0       600.0
CONM2   112     112     0       400.0
CONM2   121     121     0       600.0
CONM2   122     122     0       400.0
$                                                                       $
```

Listing 7-22 Input Files for FSW Airplane with Bodies (Continued)

```
$                        * LEFT WING MASSES *                          $
$                                                                      $
CONM2   211     211     0       600.0
CONM2   212     212     0       400.0
CONM2   221     221     0       600.0
CONM2   222     222     0       400.0
$                                                                      $
$                           * FIN MASSES *                             $
$                                                                      $
CONM2   311     311     0       60.0
CONM2   312     312     0       40.0
$                                                                      $
$                  * * STRUCTURAL PARAMETERS * *                       $
$                                                                      $
$       THE PARAM,WTMASS,GINV CAUSES ALL THE STRUCTURAL MASSES AND     $
$       MASS DENSITIES TO BE MULTIPLIED BY GINV (that is, BY ONE OVER  $
$       THE ACCELERATION OF GRAVITY).  THE DYNAMIC PRESSURE SUPPLIED   $
$       FOR AERODYNAMIC FORCE CALCULATIONS WILL NOT BE MULTIPLIED      $
$       BY GINV.                                                       $
$                                                                      $
PARAM   WTMASS  .031081
PARAM   AUNITS  .031081
$                                                                      $
$                  * * STRUCTURAL CONSTRAINTS * *                      $
$                                                                      $
$       THE SPC1 ENTRY CONSTRAINS THE LISTED GRID POINTS IN THE        $
$       SPECIFIED DOF COMPONENTS.                                      $
$                                                                      $
$       SID     C       G1      G2      G3      G4
SPC1    1       1       90
$                                                                      $
$       THE SUPORT ENTRY IDENTIFIES A GRID POINT OR A SCALAR POINT     $
$       AND SPECIFIES THE DOF COMPONENTS IN WHICH THE USER DESIRES     $
$       REACTIONS TO BE APPLIED TO PREVENT RIGID BODY MOTION.  IT      $
$       THUS INVOKES THE SOLUTION OF THE BALANCE EQUATIONS TO DETER-   $
$       MINE THE REACTIONS.  IN THE STATIC AEROELASTIC SOLUTION        $
$       THE DOF COMPONENTS MUST BE CONSISTENT WITH THE UNDEFINED       $
$       VARIABLES ON THE TRIM ENTRIES.                                 $
$                                                                      $
$       ID      C
SUPORT  90      23456
$                                                                      $
$       THE OMIT1 ENTRY IDENTIFIES GRID POINTS TO BE OMITTED FROM      $
$       THE REMAINDER OF THE ANALYSIS.                                 $
$                                                                      $
$       ID      G       G       G       G
OMIT1   4       110     120     210     220     310
$                                                                      $
$                   * * * AERODYNAMIC DATA * * *                       $
$                                                                      $
$                         (LB-FT-SEC SYSTEM)                           $
$                                                                      $
$                     * * ELEMENT GEOMETRY * *                         $
$                                                                      $
$       THE AEROS ENTRY IS UNIQUE TO THE STATIC AEROELASTICITY         $
$       SOLUTION, SOL21.  ACSID IDENTIFIES THE AERO COORDINATE         $
$       SYSTEM, RCSID IDENTIFIES THE REFERENCE COORDINATE SYS-         $
$       TEM FOR RIGID BODY MOTION.  REFC IS THE REFERENCE CHORD.       $
$       REFB IS THE REFERENCE SPAN.  REFS IS THE REFERENCE WING        $
$       AREA.  SYMXZ AND SYMXY ARE SYMMETRY KEYS.                      $
$                                                                      $
$       ACSID   RCSID   REFC    REFB    REFS    SYMXZ   SYMXY
AEROS   1       100     10.0    40.0    400.0
$                                                                      $
$       THIS CORD2R ENTRY DEFINES THE AERO COORDINATE SYSTEM           $
$       FLAGGED BY THE AEROS ENTRY.  THE ORIGIN IS AT THE CANARD       $
$       QUARTER CHORD.  LISTED ARE THE ORIGIN, A POINT ALONG THE       $
$       Z AXIS AND A POINT IN THE X-Z PLANE, ALL IN THE RID            $
$       COORDINATE SYSTEM.                                             $
$                                                                      $
$       CID     RID     A1      A2      A3      B1      B2      B3
CORD2R  1       0       12.5    0.      0.      12.5    0.      10.     +CRD1
$       C1      C2      C3
+CRD1   20.     0.      0.
$                                                                      $
$       THIS CORD2R ENTRY DEFINES THE NACA COORDINATE SYSTEM TO        $
$       WHICH ALL THE STABILITY DERIVATIVES AND TRIM CONDITIONS        $
$       WILL BE REFERENCED.                                            $
$                                                                      $
$       CID     RID     A1      A2      A3      B1      B2      B3
CORD2R  100     0       15.0    0.0     0.0     15.0    0.0     -10.0   +CRD100
$       C1      C2      C3
+CRD100 0.0     0.0     0.0
$                                                                      $
$                                                                      $
```

Listing 7-22 Input Files for FSW Airplane with Bodies (Continued)

```
$                       * WING AERODYNAMIC MODEL *                       $
$                                                                        $
$        THE CAERO1 ENTRY IS USED FOR DOUBLET-LATTICE AERODYNAMICS.      $
$        LISTED ARE ITS PAERO ENTRY ID AND THE COORDINATE SYSTEM         $
$        FOR LOCATING THE INBOARD AND OUTBOARD LEADING EDGE POINTS       $
$        (1 AND 4).  NSPAN AND NCHORD, OR LSPAN AND LCHORD, ARE          $
$        USED TO PARTITION THE WING INTO AERODYNAMIC PANELS,             $
$        THE FORMER FOR UNIFORMLY SPACED PANELS AND THE LATTER           $
$        FOR NON-UNIFORMLY SPACED PANELS.  IGID IS THE ID OF ITS         $
$        ASSOCIATED INTERFERENCE GROUP.  THE CONTINUATION ENTRY          $
$        DEFINES POINTS 1 AND 4, THE ROOT CHORD AND TIP CHORD.           $
$        THE BOXES FORMED BY THE GRID LINES WILL BE NUMBERED             $
$        BEGINNING WITH EID SO CHOOSE A NUMBER THAT IS UNIQUE,           $
$        AND IS GREATER THAN ALL STRUCTURAL GRID, SCALAR AND             $
$         EXTRA POINT IDS.                                               $
$                                                                        $
$                     * RIGHT INBOARD WING *
$       EID     PID     CP      NSPAN   NCHORD  LSPAN   LCHORD  IGID
CAERO1  1104    1000            3       4                       1       +CARW2
$      ( FWD LEFT POINT  )      CHORD  ( FWD RIGHT POINT   )    CHORD
$       X1      Y1      Z1      X12     X4      Y4      Z4      X14
+CARW2  23.55662+2.5    0.      10.     19.22650+10.    0.      10.
$                                                                        $
$                     * RIGHT OUTBOARD WING *
$       EID     PID     CP      NSPAN   NCHORD  LSPAN   LCHORD  IGID
CAERO1  1116    1000            4       4                       1       +CARW3
$      ( FWD LEFT POINT  )      CHORD  ( FWD RIGHT POINT   )    CHORD
$       X1      Y1      Z1      X12     X4      Y4      Z4      X14
+CARW3  19.22650+10.    0.      10.     13.45299+20.    2.      10.
$                                                                        $
$                                                                        $
$                           * LEFT OUTBOARD WING *
CAERO1  2100    1000            4       4                       1       +CALW1
+CALW1  13.45299-20.    2.      10.     19.22650-10.    0.      10.
$                                                                        $
$                           * LEFT INBOARD WING *
CAERO1  2116    1000            3       4                       1       +CALW2
+CALW2  19.22650-10.    0.      10.     23.55662-2.5    0.      10.
$                                                                        $
$
$                          * CANARD AERODYNAMIC MODEL *                  $
$                                                                        $
$                            * RIGHT OUTBOARD SIDE *
CAERO1  1000    1000    900             4       1000            1       +CARC2
+CARC2  0.0     2.0     0.0     10.0    0.0     5.0     0.0     10.
$                                                                        $
AEFACT  1000    0.0     0.16667 1.0
$
$                            * LEFT OUTBOARD SIDE *
CAERO1  2000    1000    900             4       2000            1       +CALC1
+CALC1  0.0     -5.0    0.0     10.     0.0     -2.0    0.0     10.
$                                                                        $
AEFACT  2000    0.0     0.83333 1.0
$
$                                                                        $
$                       * FIN AERODYNAMIC MODEL *                        $
$                                                                        $
CAERO1  3100    1000            3       4                       1       +CA1FI1
+CA1FI1 30.7735 0.      10.     10.     26.44334 0.0    2.5     10.
$                                                                        $
$
$
$                       * FUSELAGE AERODYNAMIC MODEL *
$
$       PID     B1      B2      B3      B4      B5      B6
PAERO1  1000    4000    4510    4610
$
$       EID     PID     CP      NSB     NINT    LSB     LINT    IGID    +CA2
CAERO2  4000    4020            8       8                       1       +CA2F
$       X1      Y1      Z1      X12
+CA2F   -5.0    0.0     0.0     40.0
$                                                                       $
$       PID     ORIENT  WIDTH   AR      LRSB    LRIB    LTH1    LTH2    +PA2
PAERO2  4020    ZY      2.5     1.0     4015            4018            +PA2F
$       THI1    THN1    THI2    THN2
+PA2F   1       8
$
$                     * (LRSB) SLENDER BODY HALF-WIDTHS *
$
AEFACT  4015    0.0     1.111   1.778   2.0     2.0     2.0     2.5     +LRSBF
+LRSBF  2.5     2.5
$
$                       * (LTH1 & 2) THETA ARRAYS *
$
AEFACT  4018    45.     135.    225.    315.
$
$
```

Listing 7-22 Input Files for FSW Airplane with Bodies (Continued)

```
$                         * RIGHT PYLON/STORE AERODYNAMIC MODEL *
$
$                               * RIGHT PYLON *
CAERO1  3500    1000            1       2                       1       +CA1RP
+CA1RP  21.72650+10.0   0.      5.0     21.72650+10.0   -1.0    5.0
$                                                                       $
$                               * RIGHT STORE *
$
$       EID     PID     CP      NSB     NINT    LSB     LINT    IGID    +CA2
CAERO2  4510    4520            4       4                       1       +CA2RS
$       X1      Y1      Z1      X12
+CA2RS  19.22650+10.0   -1.5    10.0
$                                                                       $
$       PID     ORIENT  WIDTH   AR      LRSB    LRIB    LTH1    LTH2    +PA2
PAERO2  4520    ZY      0.5     1.0     4515            4018            +PA2RS
$       THI1    THN1    THI2    THN2
+PA2RS  1       4
$
$                       * (LRSB) SLENDER BODY HALF-WIDTHS *
$
AEFACT  4515    0.0     0.5     0.5     0.5     0.0
$
$
$                         * LEFT PYLON/STORE AERODYNAMIC MODEL *
$
$                               * LEFT PYLON *
CAERO1  3600    1000            1       2                       1       +CA1LP
+CA1LP  21.72650-10.0   0.      5.0     21.72650-10.0   -1.0    5.0
$                                                                       $
$                               * LEFT STORE *
$
$       EID     PID     CP      NSB     NINT    LSB     LINT    IGID    +CA2
CAERO2  4610    4520            4       4                       1       +CA2LS
$       X1      Y1      Z1      X12
+CA2LS  19.22650-10.0   -1.5    10.0
$                                                                       $
$
$                                                                       $
$                 * * SPLINE FIT ON THE LIFTING SURFACES * *            $
$                                                                       $
$                       * BEAM SPLINE FIT ON THE WING *                 $
$                                                                       $
$       THE SPLINE2 ENTRY SPECIFIES A BEAM SPLINE FOR INTERPOLAT-       $
$       ION OVER THE REGION OF THE CAERO ENTRY (ID1 AND ID2 ARE         $
$       THE FIRST AND LAST BOXES IN THIS REGION).  SETG REFERS          $
$       TO A SET1 ENTRY WHERE THE STRUCTURAL GRID POINTS ARE            $
$       DEFINED.  DZ AND DTOR ARE SMOOTHING CONSTANTS FOR LINEAR        $
$       ATTACHMENT AND TORSIONAL FLEXIBILITIES.  CID IDENTIFIES         $
$       THE CORD2R ENTRY THAT DEFINES THE SPLINE AXIS.  DTHX AND        $
$       DTHY ARE ROTATIONAL ATTACHMENT FLEXIBILITIES (-1. SPECIFIES     $
$       NO ATTACHMENT).                                                 $
$                                                                       $
$                             * RIGHT INBOARD WING *                    $
$       EID     CAERO   ID1     ID2     SETG    DZ      DTOR    CID
SPLINE2 1602    1104    1104    1115    1101    0.      1.      2       +SPRW2
$       DTHX    DTHY
+SPRW2  -1.     -1.
$                                                                       $
$                             * RIGHT OUTBOARD WING *                   $
$       EID     CAERO   ID1     ID2     SETG    DZ      DTOR    CID
SPLINE2 1603    1116    1116    1131    1102    0.      1.      3       +SPRW3
$       DTHX    DTHY
+SPRW3  -1.     -1.
$                                                                       $
$       THE SET1 ENTRY DEFINES THE SETS OF STRUCTURAL GRID POINTS       $
$       TO BE USED BY THE BEAM SPLINE FOR INTERPOLATION.                $
$                                                                       $
$       SID     G1      G2      G3      G4
SET1    1101    100     111     112     115
SET1    1102    115     121     122
$                                                                       $
$                             * LEFT OUTBOARD WING *                    $
$       EID     CAERO   ID1     ID2     SETG    DZ      DTOR    CID
SPLINE2 2601    2100    2100    2115    2102    0.      1.      30      +SPLW1
$       DTHX    DTHY
+SPLW1  -1.     -1.
$                                                                       $
$                             * LEFT INBOARD WING *                     $
$       EID     CAERO   ID1     ID2     SETG    DZ      DTOR    CID
SPLINE2 2602    2116    2116    2127    2101    0.      1.      20      +SPLW2
$       DTHX    DTHY
+SPLW2  -1.     -1.
$                                                                       $
$       THE SET1 ENTRY DEFINES THE SETS OF STRUCTURAL GRID POINTS       $
$       TO BE USED BY THE BEAM SPLINE FOR INTERPOLATION.                $
$                                                                       $
```

Listing 7-22 Input Files for FSW Airplane with Bodies (Continued)

```
$       SID     G1      G2      G3      G4
SET1    2101    100     211     212     215
SET1    2102    215     221     222
$                                                                       $
$
$                  * BEAM SPLINE FIT ON THE CANARD *                    $
$                                                                       $
$                                                                       $
$                       * RIGHT OUTBOARD SIDE *                         $
SPLINE2 1502    1000    1000    1007    1000    0.      1.      90      +SPRC2
+SPRC2  0.0     0.0
$                                                                       $
SET1    1000    88      89      91      92
$                                                                       $
$                       * LEFT OUTBOARD SIDE *                          $
SPLINE2 2501    2000    2000    2007    1000    0.      1.      90      +SPLC1
+SPLC1  0.0     0.0
$                                                                       $
$                    * BEAM SPLINE FIT ON THE FIN *                     $
$                                                                       $
SPLINE2 3100    3100    3100    3111    3100    0.      1.      300     +SP2FI1
+SP2FI1 -1.     -1.
$                                                                       $
SET1    3100    99      100     311     312
$                                                                       $
$                    * BEAM SPLINE FIT ON THE PYLONS *                  $
$                                                                       $
$                           * RIGHT PYLON *
$
SPLINE2 4520    3500    3500    3501    4521    0.      1.      450     +SP2RP
+SP2RP  -1.     -1.
$                                                                       $
SET1    4521    115     150     151
$                                                                       $
$                           * LEFT PYLON *
$
SPLINE2 4620    3600    3600    3601    4621    0.      1.      460     +SP2LP
+SP2LP  -1.     -1.
$                                                                       $
SET1    4621    215     250     251
$                                                                       $
$
$                    * BEAM SPLINE FIT ON THE BODIES *                  $
$                                                                       $
$                           * FUSELAGE *
$
SPLINE2 4000    4000    4000    4007    4001    0.      1.              +SP2F
+SP2F           -1.
$                                                                       $
SET1    4001    97      98      99      100
$                                                                       $
$                                                                       $
$                           * RIGHT STORE *
$
SPLINE2 4525    4510    4510    4513    4525    0.      1.              +SP2RS
+SP2RS          -1.
$                                                                       $
SET1    4525    150     151
$                                                                       $
$                                                                       $
$                           * LEFT STORE *
$
SPLINE2 4625    4610    4610    4613    4625    0.      1.              +SP2LS
+SP2LS          -1.
$                                                                       $
SET1    4625    250     251
$                                                                       $
$       THE CORD2R ENTRY DEFINES THE COORDINATE SYSTEM IN WHICH THE     $
$       BEAM SPLINE EXTENDS ALONG THE WING Y-AXIS.  IT LISTS THE        $
$       ORIGIN, A POINT ALONG THE Z-AXIS AND A POINT IN THE X-Z         $
$        PLANE.                                                         $
$                                                                       $
$                  * INBOARD RIGHT WING SPLINE AXIS *                   $
$                                                                       $
$       CID     CS      A1      A2      A3      B1      B2      B3
CORD2R  2       0       30.     0.      0.      30.     0.      10.     +CRD2RW
$       C1      C2      C3
+CRD2RW 38.66025+5.0    0.
$                                                                       $
$                     * OUTBOARD RIGHT WING SPLINE AXIS *               $
$                                                                       $
$       CID     CS      A1      A2      A3      B1      B2      B3
CORD2R  3       0       24.22650+10.    0.      25.07982 8.293369.853293+CRD2ORW
$       C1      C2      C3
+CRD2ORW34.2265015.77350+0.
$                                                                       $
```

Listing 7-22 Input Files for FSW Airplane with Bodies (Continued)

```
$                          * INBOARD LEFT WING SPLINE AXIS *           $
$                                                                      $
$       CID     CS      A1      A2      A3      B1      B2      B3
CORD2R  20      0       30.0    0.      0.      30.     0.      10.     +CRD2ILW
$       C1      C2      C3
+CRD2ILW38.66025-5.0    0.
$                                                                      $
$                          * OUTBOARD LEFT WING SPLINE AXIS *          $
$                                                                      $
$       CID     CS      A1      A2      A3      B1      B2      B3
CORD2R  30      0       24.22650-10.    0.      25.07982-8.293369.853293+CRD2OLW
$       C1      C2      C3
+CRD2OLW34.22650-15.7735+0.
$                                                                      $
$                            * FIN SPLINE AXIS *                       $
$                                                                      $
CORD2R  300     0       30.0    0.      0.      30.0    10.0    0.      +CRD2FI
+CRD2FI 20.0    0.0     5.7735
$
$                         * RIGHT PYLON SPLINE AXIS *
$
CORD2R  450     0       24.22650+10.0   0.      24.22650+20.0   0.0     +CRD2RP
+CRD2RP 30.0    20.0    0.0
$
$                         * LEFT PYLON SPLINE AXIS *                   $
$
CORD2R  460     0       24.22650-10.0   0.      24.22650+20.0   0.0     +CRD2LP
+CRD2LP 30.0    20.0    0.0
$
$                                                                      $
$                   * CONTROL SURFACE DEFINITION *                     $
$                                                                      $
$       THE AESURF ENTRY DEFINES AN AERODYNAMIC CONTROL SURFACE.       $
$       LISTED ARE THE ALPHANUMERIC NAME OF THE SURFACE, THE ID        $
$       OF A COORDINATE SYSTEM THAT DEFINES THE HINGE LINE AND         $
$        THE ID OF AN AELIST ENTRY.                                    $
$                                                                      $
$       ID      LABEL   CID1    ALID1   CID2    ALID2
AESURF  505     ELEV    90      1000    90      2000
AESURF  517     AILERON 110     1100    210     2100
AESURF  518     RUDDER  301     3000
$                                                                      $
$       THE AELIST ENTRY LISTS AERODYNAMIC BOXES THAT LIE ON THE       $
$        CONTROL SURFACE.                                              $
$                                                                      $
$       SID     E1      E2      E3      ETC
AELIST  1000    1000    THRU    1007
AELIST  2000    2000    THRU    2007
AELIST  1100    1119    1123    1127    1131
AELIST  2100    2103    2107    2111    2115
AELIST  3000    3103    3107    3111
$                                                                      $
$                    * CONTROL SURFACE HINGE LINES *                   $
$                                                                      $
$                             * CANARD *                               $
$       THE COORDINATE SYSTEM, CORD2R,1, REFERENCED BY THE AEROS ENTRY $
$       IS THE CANARD HINGE LINE, AND NEEDS NO FURTHER DEFINITION      $
$                                                                      $
$                          * RIGHT AILERON *                           $
CORD2R  110     0       26.7265 10.0    0.      26.7265 10.0    -10.0   +CRD2RA
+CRD2RA 36.7265 15.7735 0.
$                                                                      $
$                          * LEFT AILERON *                            $
CORD2R  210     0       26.7265 -10.0   0.      26.7265 -10.0   10.0    +CRD2LA
+CRD2LA 36.7265 -15.7735 0.
$                                                                      $
$                               * RUDDER *                             $
CORD2R  301     0       32.5    0.      0.      32.5    -10.    0.0     +CRD2R
+CRD2R  22.5    0.      5.7735
$                                                                      $
$                    * * USER SUPPLIED INPUT DATA * *                  $
$                                                                      $
$       THE DMI ENTRY ACCOMMODATES DIRECT INPUT OF USER SUPPLIED       $
$       MATRICES OF DATA.  LISTED ARE THE NAME OF THE MATRIX, THE      $
$       FORM OF MATRIX (IN THIS CASE DIAGONAL), THE TYPE OF DATA       $
$       (IN THIS CASE REAL SINGLE PRECISION), BEING INPUT AND THE      $
$       TYPE EXPECTED AT OUTPUT (IN THIS CASE TO BE DETERMINED         $
$       INTERNALLY).  M IS THE NUMBER OF ROWS AND N IS THE NUMBER      $
$       OF COLUMNS.  THE DATA IS EXPECTED BY COLUMNS.  THE CONTIN-     $
$       UATION ENTRY LISTS THE COLUMN NO., THE ROW NO. OF THE FIRST    $
$       NON-ZERO ELEMENT AND THE FOLLOWING ELEMENTS IN THAT COLUMN.    $
$                                                                      $
$    * INITIAL DOWNWASHES (for example, DUE TO INCIDENCE,TWIST OR CAMBER) *  $
$                                                                      $
```

Listing 7-22 Input Files for FSW Airplane with Bodies (Continued)

```
$       NAME    "0"     FORM    TIN     TOUT            M       N
DMI     W2GJ    0       2       1       0               152     1
$       NAME    J       I1      A(I1,J) A(I1+1,J)...
DMI     W2GJ    1       9       .0017453THRU    20      21      .0017114+DM1
+DM1    THRU    36      45      .0017114THRU    60      61      .0017453+DM2
+DM2    THRU    72
$
$                                                                       $
$                  * * * SOLUTION SPECIFICATIONS * * *                  $
$                                                                       $
$                       * * AERODYNAMIC DOFS * *                        $
$                                                                       $
$       THE AESTAT CARD LISTS TRIM VARIABLES USED TO SPECIFY            $
$       RIGID BODY MOTIONS.  THESE AND THE CONTROL SURFACE              $
$       ROTATIONS MAKE UP THE VARIABLES IN THE EQUATIONS OF             $
$        MOTION.                                                        $
$                                                                       $
$       ID      LABEL
AESTAT  501     ANGLEA
AESTAT  502     PITCH
AESTAT  503     URDD3
AESTAT  504     URDD5
AESTAT  511     SIDES
AESTAT  512     YAW
AESTAT  513     ROLL
AESTAT  514     URDD2
AESTAT  515     URDD4
AESTAT  516     URDD6
$                                                                       $
$                        * * TRIM CONDITIONS * *                        $
$                                                                       $
$       THE TRIM ENTRY SPECIFIES CONSTRAINTS FOR THE TRIM VARIABLES     $
$       LISTED ON THE AESTAT AND AESURF ENTRIES.  LISTED ARE ITS ID,    $
$       THE MACH NUMBER, DYNAMIC PRESSURE AND PAIRS OF TRIM VARI-       $
$       ABLES AND THEIR CONSTRAINED VALUES.  THOSE THAT ARE NOT         $
$       HELD FIXED MUST BE CONSTRAINED BY REACTION FORCES STIPU-        $
$       LATED ON THE SUPORT ENTRY.  SEE SECTION 3.5.3 OF THE THEO-      $
$        RETICAL MANUAL FOR MORE DETAILS.                               $
$                                                                       $
$       TRIM CONDITION 1: LEVEL FLIGHT AT HIGH DYNAMIC PRESSURE         $
$                                                                       $
TRIM    1       0.9     1200.0  PITCH   0.      URDD3   -1.0            +TR1A
+TR1A   URDD5   0.      AILERON 0.      RUDDER  0.      URDD2   0.      +TR1B
+TR1B   URDD4   0.      URDD6   0.
$                                                                       $
$                                 * * *                                 $
  ENDDATA
  INPUT BULK DATA CARD COUNT =     722
```

Main Index

Listing 7-23 Sorted Bulk Data Entries for FSW Airplane with Bodies

```
    EXAMPLE HA144F: FSW WITH FUSELAGE, 3 CONTROLS & 2 STORES
PAGE   18
     UNSYMMETRIC FLIGHT CONDITIONS, DOUBLET-LATTICE AERO
    FULL-SPAN MODEL WITH DISPLACED CANARD
                                         S O R T E D   B U L K   D A T A   E C H O
               CARD
               COUNT      .  1  ..  2  ..  3  ..  4  ..  5  ..  6  ..  7  ..  8  ..  9  ..  10  .
                    1-        AEFACT  1000    0.0     0.16667 1.0
                    2-        AEFACT  2000    0.0     0.83333 1.0
                    3-        AEFACT  4015    0.0     1.111   1.778   2.0     2.0     2.0     2.5     +LRSBF
                    4-        +LRSBF  2.5     2.5
                    5-        AEFACT  4018    45.     135.    225.    315.
                    6-        AEFACT  4515    0.0     0.5     0.5     0.5     0.0
                    7-        AELIST  1000    1000    THRU    1007
                    8-        AELIST  1100    1119    1123    1127    1131
                    9-        AELIST  2000    2000    THRU    2007
                   10-        AELIST  2100    2103    2107    2111    2115
                   11-        AELIST  3000    3103    3107    3111
                   12-        AEROS   1       100     10.0    40.0    400.0
                   13-        AESTAT  501     ANGLEA
                   14-        AESTAT  502     PITCH
                   15-        AESTAT  503     URDD3
                   16-        AESTAT  504     URDD5
                   17-        AESTAT  511     SIDES
                   18-        AESTAT  512     YAW
                   19-        AESTAT  513     ROLL
                   20-        AESTAT  514     URDD2
                   21-        AESTAT  515     URDD4
                   22-        AESTAT  516     URDD6
                   23-        AESURF  505     ELEV    90      1000    90      2000
                   24-        AESURF  517     AILERON 110     1100    210     2100
                   25-        AESURF  518     RUDDER  301     3000
                   26-        CAERO1  1000    1000    900             4       1000            1       +CARC2
                   27-        +CARC2  0.0     2.0     0.0     10.0    0.0     5.0     0.0     10.
                   28-        CAERO1  1104    1000            3       4                       1       +CARW2
                   29-        +CARW2  23.55662+2.5    0.      10.     19.22650+10.    0.      10.
                   30-        CAERO1  1116    1000            4       4                       1       +CARW3
                   31-        +CARW3  19.22650+10.    0.      10.     13.45299+20.    2.      10.
                   32-        CAERO1  2000    1000    900             4       2000            1       +CALC1
                   33-        +CALC1  0.0     -5.0    0.0     10.     0.0     -2.0    0.0     10.
                   34-        CAERO1  2100    1000            4       4                       1       +CALW1
                   35-        +CALW1  13.45299-20.    2.      10.     19.22650-10.    0.      10.
                   36-        CAERO1  2116    1000            3       4                       1       +CALW2
                   37-        +CALW2  19.22650-10.    0.      10.     23.55662-2.5    0.      10.
                   38-        CAERO1  3100    1000            3       4                       1       +CA1FI1
                   39-        +CA1FI1 30.7735 0.      10.     10.     26.443340.0     2.5     10.
                   40-        CAERO1  3500    1000            1       2                       1       +CA1RP
                   41-        +CA1RP  21.72650+10.0   0.      5.0     21.72650+10.0   -1.0    5.0
                   42-        CAERO1  3600    1000            1       2                       1       +CA1LP
                   43-        +CA1LP  21.72650-10.0   0.      5.0     21.72650-10.0   -1.0    5.0
                   44-        CAERO2  4000    4020            8       8                       1       +CA2F
                   45-        +CA2F   -5.0    0.0     0.0     40.0
                   46-        CAERO2  4510    4520            4       4                       1       +CA2RS
                   47-        +CA2RS  19.22650+10.0   -1.5    10.0
                   48-        CAERO2  4610    4520            4       4                       1       +CA2LS
                   49-        +CA2LS  19.22650-10.0   -1.5    10.0
                   50-        CBAR    89      101     88      89      0.      0.      1.
                   51-        CBAR    90      101     890     90      0.      0.      1.
                   52-        CBAR    91      101     90      910     0.      0.      1.
                   53-        CBAR    92      101     91      92      0.      0.      1.
                   54-        CBAR    100     100     90      99      0.      0.      1.
                   55-        CBAR    101     100     97      98      0.      0.      1.
                   56-        CBAR    102     100     98      90      0.      0.      1.
                   57-        CBAR    103     100     99      100     0.      0.      1.
                   58-        CBAR    110     101     100     110     0.      0.      1.
                   59-        CBAR    115     101     110     115     0.      0.      1.
                   60-        CBAR    120     101     115     120     0.      0.      1.
                   61-        CBAR    150     101     150     151     0.      0.      1.
                   62-        CBAR    151     101     151     115     1.      0.      0.
                   63-        CBAR    210     101     100     210     0.      0.      1.
                   64-        CBAR    215     101     210     215     0.      0.      1.
                   65-        CBAR    220     101     215     220     0.      0.      1.
                   66-        CBAR    250     101     250     251     0.      0.      1.
                   67-        CBAR    251     101     251     215     1.      0.      0.
                   68-        CBAR    310     101     100     310     0.      0.      1.
                   69-        CONM2   97      97      0       3000.0
                   70-        CONM2   98      98      0       3000.0
                   71-        CONM2   99      99      0       3000.0
                   72-        CONM2   100     100     0       3000.0
                   73-        CONM2   111     111     0       600.0
                   74-        CONM2   112     112     0       400.0
                   75-        CONM2   121     121     0       600.0
```

Listing 7-23 Sorted Bulk Data Entries for FSW Airplane with Bodies (Continued)

```
CONM2   122     122     0       400.0
CONM2   211     211     0       600.0
CONM2   212     212     0       400.0
CONM2   221     221     0       600.0
CONM2   222     222     0       400.0
CONM2   311     311     0       60.0
CONM2   312     312     0       40.0
CORD2R  1       0       12.5    0.      0.      12.5    0.      10.     +CRD1
+CRD1   20.     0.      0.
CORD2R  2       0       30.     0.      0.      30.     0.      10.     +CRD2RW
+CRD2RW 38.66025+5.0    0.
CORD2R  3       0       24.22650+10.    0.      25.079828.29336 9.853293+CRD2ORW
+CRD2ORW34.2265015.77350+0.
CORD2R  20      0       30.0    0.      0.      30.     0.      10.     +CRD2ILW
+CRD2ILW38.66025-5.0    0.
CORD2R  30      0       24.22650-10.    0.      25.07982-8.293369.853293+CRD2OLW
+CRD2OLW34.22650-15.7735+0.
CORD2R  90      900     5.0     0.0     0.0     5.0     0.0     15.0    +CRD90C
+CRD90C 20.0    0.0     0.0
CORD2R  100     0       15.0    0.0     0.0     15.0    0.0     -10.0   +CRD100
+CRD100 0.0     0.0     0.0
CORD2R  110     0       26.7265 10.0    0.      26.7265 10.0    -10.0   +CRD2RA
+CRD2RA 36.7265 15.7735 0.
CORD2R  210     0       26.7265 -10.0   0.      26.7265 -10.0   10.0    +CRD2LA
+CRD2LA 36.7265 -15.77350.
CORD2R  300     0       30.0    0.      0.      30.0    10.0    0.      +CRD2FI
+CRD2FI 20.0    0.0     5.7735
CORD2R  301     0       32.5    0.      0.      32.5    -10.    0.0     +CRD2R
+CRD2R  22.5    0.      5.7735
CORD2R  450     0       24.22650+10.0   0.      24.22650+20.0   0.0     +CRD2RP
+CRD2RP 30.0    20.0    0.0
CORD2R  460     0       24.22650-10.0   0.      24.22650+20.0   0.0     +CRD2LP
+CRD2LP 30.0    20.0    0.0
CORD2R  900             10.0    0.0     1.5     10.0    0.0     15.0    +CRD900C
+CRD900C20.0    0.0     1.5
DMI     W2GJ    0       2       1       0               152     1
DMI     W2GJ    1       9       .0017453THRU    20      21      .0017114+DM1
+DM1    THRU    36      45      .0017114THRU    60      61      .0017453+DM2
+DM2    THRU    72
GRID    88      900     5.0     -5.0    0.0
GRID    89      900     5.0     -2.0    0.0
GRID    90              15.     0.      0.
GRID    91      900     5.0     2.0     0.0
GRID    92      900     5.0     5.0     0.0
GRID    97              0.      0.      0.
GRID    98              10.     0.      0.
GRID    99              20.     0.      0.
GRID    100             30.     0.      0.
GRID    110             27.11325+5.     0.
GRID    111             24.61325+5.     0.
GRID    112             29.61325+5.     0.
GRID    115             24.22650+10.    0.
GRID    120             21.33975+15.    1.
GRID    121             18.83975+15.    1.
GRID    122             23.83975+15.    1.
GRID    150             19.22650+10.    -1.5
GRID    151             24.22650+10.    -1.5
GRID    210             27.11325-5.     0.
GRID    211             24.61325-5.     0.
GRID    212             29.61325-5.     0.
GRID    215             24.22650-10.    0.
GRID    220             21.33975-15.    1.
GRID    221             18.83975-15.    1.
GRID    222             23.83975-15.    1.
GRID    250             19.22650-10.    -1.5
GRID    251             24.22650-10.    -1.5
GRID    310             32.88675+0.     5.
GRID    311             30.38675+0.     5.
GRID    312             35.38675+0.     5.
GRID    890             15.     -2.0    0.
GRID    910             15.     +2.0    0.
MAT1    1       1.44+9  5.40+8
MPC     10      89      1       1.0     890     1       -1.0
MPC     10      89      2       1.0     890     2       -1.0
MPC     10      89      3       1.0     890     3       -1.0
```

Main Index

Listing 7-23 Sorted Bulk Data Entries for FSW Airplane with Bodies (Continued)

```
151-        MPC     10      89      4       1.0     890     4       -1.0
152-        MPC     10      89      5       1.0     890     5       -1.0
153-        MPC     10      89      6       1.0     890     6       -1.0
154-        MPC     10      91      1       1.0     910     1       -1.0
155-        MPC     10      91      2       1.0     910     2       -1.0
156-        MPC     10      91      3       1.0     910     3       -1.0
157-        MPC     10      91      4       1.0     910     4       -1.0
158-        MPC     10      91      5       1.0     910     5       -1.0
159-        MPC     10      91      6       1.0     910     6       -1.0
160-        OMIT1   4       110     120     210     220     310
161-        PAERO1  1000    4000    4510    4610
162-        PAERO2  4020    ZY      2.5     1.0     4015            4018            +PA2F
163-        +PA2F   1       8
164-        PAERO2  4520    ZY      0.5     1.0     4515            4018            +PA2RS
165-        +PA2RS  1       4
166-        PARAM   AUNITS  .031081
167-        PARAM   WTMASS  .031081
168-        PBAR    100     1       4.0     .347222 .30     1.0                     +PB1F
169-        +PB1F   1.0     1.0     1.0     -1.0    -1.0    1.0     -1.0    -1.0    +PB2F
170-        +PB2F                   0.0
171-        PBAR    101     1       1.5     0.173611+2.0    0.462963                +PB1W
172-        +PB1W   0.5     3.0     0.5     -3.0    -0.5    3.0     -0.5    -3.0    +PB2W
173-        +PB2W                   0.0
174-        RBAR    111     110     111     123456
175-        RBAR    112     110     112     123456
176-        RBAR    121     120     121     123456
177-        RBAR    122     120     122     123456
178-        RBAR    211     210     211     123456
179-        RBAR    212     210     212     123456
180-        RBAR    221     220     221     123456
181-        RBAR    222     220     222     123456
182-        RBAR    311     310     311     123456
183-        RBAR    312     310     312     123456
184-        SET1    1000    88      89      91      92
185-        SET1    1101    100     111     112     115
186-        SET1    1102    115     121     122
187-        SET1    2101    100     211     212     215
188-        SET1    2102    215     221     222
189-        SET1    3100    99      100     311     312
190-        SET1    4001    97      98      99      100
191-        SET1    4521    115     150     151
192-        SET1    4525    150     151
193-        SET1    4621    215     250     251
194-        SET1    4625    250     251
195-        SPC1    1       1       90
196-        SPLINE2 1502    1000    1000    1007    1000    0.      1.      90      +SPRC2
197-        +SPRC2  0.0     0.0
198-        SPLINE2 1602    1104    1104    1115    1101    0.      1.      2       +SPRW2
199-        +SPRW2  -1.     -1.
200-        SPLINE2 1603    1116    1116    1131    1102    0.      1.      3       +SPRW3
201-        +SPRW3  -1.     -1.
202-        SPLINE2 2501    2000    2000    2007    1000    0.      1.      90      +SPLC1
203-        +SPLC1  0.0     0.0
204-        SPLINE2 2601    2100    2100    2115    2102    0.      1.      30      +SPLW1
205-        +SPLW1  -1.     -1.
206-        SPLINE2 2602    2116    2116    2127    2101    0.      1.      20      +SPLW2
207-        +SPLW2  -1.     -1.
208-        SPLINE2 3100    3100    3100    3111    3100    0.      1.      300     +SP2FI1
209-        +SP2FI1 -1.     -1.
210-        SPLINE2 4000    4000    4000    4007    4001    0.      1.              +SP2F
211-        +SP2F           -1.
212-        SPLINE2 4520    3500    3500    3501    4521    0.      1.      450     +SP2RP
213-        +SP2RP  -1.     -1.
214-        SPLINE2 4525    4510    4510    4513    4525    0.      1.              +SP2RS
215-        +SP2RS          -1.
216-        SPLINE2 4620    3600    3600    3601    4621    0.      1.      460     +SP2LP
217-        +SP2LP  -1.     -1.
218-        SPLINE2 4625    4610    4610    4613    4625    0.      1.              +SP2LS
219-        +SP2LS          -1.
220-        SUPORT  90      23456
221-        TRIM    1       0.9     1200.0  PITCH   0.      URDD3   -1.0            +TR1A
222-        +TR1A   URDD5   0.      AILERON 0.      RUDDER  0.      URDD2   0.      +TR1B
223-        +TR1B   URDD4   0.      URDD6   0.
 ENDDATA
 TOTAL COUNT=       224
```

Listing 7-24 Output for FSW Airplane with Bodies

```
EXAMPLE HA144F: FSW WITH FUSELAGE, 3 CONTROLS & 2 STORES                                                   PAGE    36
  UNSYMMETRIC FLIGHT CONDITIONS, DOUBLET-LATTICE AERO
 FULL-SPAN MODEL WITH DISPLACED CANARD                                                                    SUBCASE 1
N O N - D I M E N S I O N A L   S T A B I L I T Y   A N D   C O N T R O L   D E R I V A T I V E   C O E F F I C I E N T S

                                    MACH = 9.0000E-01                  Q = 1.2000E+03

            TRANSFORMATION FROM BASIC TO REFERENCE COORDINATES:
          { X }         [ -1.0000   0.0000   0.0000  ]  { X }         { 1.5000E+01 }
          { Y }    =    [  0.0000   1.0000   0.0000  ]  { Y }     +   { 0.0000E+00 }
          { Z }REF      [  0.0000   0.0000  -1.0000  ]  { Z }BAS      { 0.0000E+00 }

TRIM VARIABLE         COEFFICIENT              RIGID                            ELASTIC

                                        UNSPLINED        SPLINED          RESTRAINED       UNRESTRAINED
INTERCEPT                CX            0.000000E+00     0.000000E+00       0.000000E+00     0.000000E+00
                         CY           -1.299226E-10    -1.299225E-10      -1.366476E-10    -2.059599E-10
                         CZ           -7.502087E-03    -7.502087E-03      -9.901986E-03    -1.222185E-02
                         CMX           3.987231E-10     3.987492E-10       6.668876E-10     6.946241E-10
                         CMY          -4.898731E-03    -4.898731E-03      -6.364542E-03    -7.934161E-03
                         CMZ           8.584891E-11     8.596750E-11       1.202454E-10     1.436792E-10

ANGLEA                   CX            0.000000E+00     0.000000E+00       0.000000E+00     0.000000E+00
                         CY           -9.052926E-08    -9.052923E-08      -9.356474E-08    -1.382898E-07
                         CZ           -5.040129E+00    -5.040129E+00      -6.537387E+00    -7.992975E+00
                         CMX           2.459049E-07     2.459198E-07       4.120568E-07     4.299212E-07
                         CMY          -2.877635E+00    -2.877635E+00      -3.791211E+00    -4.776923E+00
                         CMZ           6.120506E-08     6.127953E-08       8.217181E-08     9.733981E-08

PITCH                    CX            0.000000E+00     0.000000E+00       0.000000E+00     0.000000E+00
                         CY           -2.032311E-07    -2.032310E-07      -1.898720E-07    -2.834348E-07
                         CZ           -1.198419E+01    -1.198419E+01      -1.324751E+01    -1.683722E+01
                         CMX           4.787124E-07     4.787220E-07       6.819224E-07     7.736392E-07
                         CMY          -9.632813E+00    -9.632813E+00      -1.035169E+01    -1.276509E+01
                         CMZ           1.120977E-07     1.123463E-07       1.328826E-07     1.711292E-07

URDD3                    CX            0.000000E+00     0.000000E+00       0.000000E+00     0.000000E+00
                         CY            0.000000E+00     0.000000E+00       5.650741E-11     0.000000E+00
                         CZ            0.000000E+00     0.000000E+00       4.103939E-03     0.000000E+00
                         CMX           0.000000E+00     0.000000E+00      -2.388719E-10     0.000000E+00
                         CMY           0.000000E+00     0.000000E+00       2.820731E-03     0.000000E+00
                         CMZ           0.000000E+00     0.000000E+00      -4.494630E-11     0.000000E+00

URDD5                    CX            0.000000E+00     0.000000E+00       0.000000E+00     0.000000E+00
                         CY            0.000000E+00     0.000000E+00       1.122847E-09     0.000000E+00
                         CZ            0.000000E+00     0.000000E+00       8.055958E-02     0.000000E+00
                         CMX           0.000000E+00     0.000000E+00      -5.010415E-09     0.000000E+00
                         CMY           0.000000E+00     0.000000E+00       5.239135E-02     0.000000E+00
                         CMZ           0.000000E+00     0.000000E+00      -9.285254E-10     0.000000E+00

ELEV                     CX            0.000000E+00     0.000000E+00       0.000000E+00     0.000000E+00
                         CY           -4.873205E-09    -4.873205E-09      -4.295436E-09    -5.451006E-09
                         CZ           -1.037880E-01    -1.037880E-01      -1.599575E-01    -1.444930E-01
                         CMX           3.078125E-09     3.078583E-09       7.282612E-09     5.192063E-09
                         CMY           2.340457E-01     2.340457E-01       1.988105E-01     2.088675E-01
                         CMZ           6.640054E-09     6.640952E-09       6.962484E-09     7.085203E-09

SIDES                    CX            0.000000E+00     0.000000E+00       0.000000E+00     0.000000E+00
                         CY           -7.493702E-01    -7.493702E-01      -7.137761E-01    -7.576051E-01
                         CZ            1.927537E-07     1.927536E-07       2.877982E-07     3.301954E-07
                         CMX          -1.354676E-01    -1.354676E-01      -1.477700E-01    -1.363622E-01
                         CMY           1.226018E-07     1.218731E-07       1.806978E-07     2.096502E-07
                         CMZ           1.900327E-01     1.900327E-01       1.774890E-01     1.929883E-01

YAW                      CX            0.000000E+00     0.000000E+00       0.000000E+00     0.000000E+00
                         CY            7.217304E-01     7.217304E-01       6.687398E-01     7.260464E-01
                         CZ           -7.310567E-08    -7.310565E-08      -9.128657E-08    -1.102763E-07
                         CMX           9.353673E-02     9.353673E-02       8.854351E-02     8.711862E-02
                         CMY          -4.576293E-08    -4.524614E-08      -5.646639E-08    -6.888230E-08
                         CMZ          -2.584813E-01    -2.584813E-01      -2.425677E-01    -2.609811E-01

ROLL                     CX            0.000000E+00     0.000000E+00       0.000000E+00     0.000000E+00
                         CY           -1.516381E-01    -1.516381E-01      -1.633789E-01    -1.590035E-01
                         CZ            5.777496E-07     5.777496E-07       1.002999E-06     1.079415E-06
                         CMX          -4.362884E-01    -4.362884E-01      -5.353552E-01    -4.651975E-01
                         CMY           3.642278E-07     3.617961E-07       6.268094E-07     6.827204E-07
                         CMZ          -9.201576E-04    -9.201575E-04      -9.716505E-03    -2.064240E-03

URDD2                    CX            0.000000E+00     0.000000E+00       0.000000E+00     0.000000E+00
                         CY            0.000000E+00     0.000000E+00       7.924410E-04     0.000000E+00
                         CZ            0.000000E+00     0.000000E+00      -2.779882E-10     0.000000E+00
                         CMX           0.000000E+00     0.000000E+00       1.503346E-04     0.000000E+00
                         CMY           0.000000E+00     0.000000E+00      -1.717070E-10     0.000000E+00
                         CMZ           0.000000E+00     0.000000E+00      -2.422818E-04     0.000000E+00
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Listing 7-24 Output for FSW Airplane with Bodies (Continued)

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URDD4                     CX         0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                          CY         0.000000E+00    0.000000E+00     1.123470E-04    0.000000E+00
                          CZ         0.000000E+00    0.000000E+00     7.046271E-09    0.000000E+00
                          CMX        0.000000E+00    0.000000E+00    -3.891726E-03    0.000000E+00
                          CMY        0.000000E+00    0.000000E+00     4.531330E-09    0.000000E+00
                          CMZ        0.000000E+00    0.000000E+00    -5.270858E-04    0.000000E+00

URDD6                     CX         0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                          CY         0.000000E+00    0.000000E+00    -2.387614E-02    0.000000E+00
                          CZ         0.000000E+00    0.000000E+00     8.716039E-09    0.000000E+00
                          CMX        0.000000E+00    0.000000E+00    -4.560409E-03    0.000000E+00
                          CMY        0.000000E+00    0.000000E+00     5.405408E-09    0.000000E+00
                          CMZ        0.000000E+00    0.000000E+00     6.942538E-03    0.000000E+00

AILERON                   CX         0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                          CY         4.911802E-02    4.911802E-02     5.241855E-02    4.971820E-02
                          CZ        -3.376502E-07   -3.376502E-07    -4.490562E-07   -4.774820E-07
                          CMX        2.803040E-01    2.803040E-01     3.064853E-01    2.662785E-01
                          CMY       -2.574724E-07   -2.565203E-07    -3.250403E-07   -3.461600E-07
                          CMZ        5.166404E-03    5.166404E-03     7.268140E-03    2.985376E-03

RUDDER                    CX         0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                          CY         2.297473E-01    2.297473E-01     1.926551E-01    2.195247E-01
                          CZ        -1.595076E-09   -1.595073E-09     1.276250E-08    1.128636E-08
                          CMX        3.164924E-02    3.164924E-02     2.404623E-02    2.562781E-02
                          CMY       -2.205325E-09   -2.185971E-09     6.709265E-09    6.050785E-09
                          CMZ       -1.170619E-01   -1.170619E-01    -1.058725E-01   -1.140591E-01

                                         INTERMEDIATE MATRIX ... HP0

                                                   COLUMN       1
              -8.813170E-11       2.237854E-03     -5.660327E-10      -1.218842E-04      -2.451579E-11

                                             INTERMEDIATE MATRIX ... HP

                                                       COLUMN      1
              -5.818967E-08       1.414439E+00      -3.489635E-07      -7.417409E-02      -1.609712E-08
                                                       COLUMN      2
              -9.743544E-08       2.969788E+00      -5.736758E-07      -2.094978E-01      -2.610605E-08
                                                       COLUMN      3
               3.281455E-11       5.562317E-03       2.026536E-10      -1.233582E-04       8.997147E-12
                                                       COLUMN      4
               6.772485E-10      -1.540755E-03       4.252287E-09      -7.445705E-03       1.867415E-10
                                                       COLUMN      5
              -3.466741E-09      -6.417216E-03      -5.491675E-09       2.293641E-03      -9.819316E-10
                                                       COLUMN      6
              -1.529903E-01      -6.875273E-08       1.071376E-01       3.554970E-09      -2.518214E-02
                                                       COLUMN      7
               1.536015E-01       2.205481E-08      -5.494779E-02      -1.111257E-09       3.605024E-02
                                                       COLUMN      8
               1.071310E-02      -2.447038E-07       4.499267E-01       1.233983E-08       7.624566E-03
                                                       COLUMN      9
              -5.622060E-03       6.714389E-11      -2.100419E-05      -3.355533E-12      -3.169009E-04
                                                       COLUMN     10
              -1.395212E-04      -1.718798E-09       2.456579E-02       8.955151E-11       1.693952E-05
                                                       COLUMN     11
               1.966925E-02      -2.092211E-09       2.716776E-03       1.057792E-10       1.675671E-02
                                                       COLUMN     12
              -5.356136E-03       1.152103E-07      -2.441650E-01      -6.919825E-09      -3.753309E-03
                                                       COLUMN     13
               7.398353E-02      -2.923241E-09      -1.039103E-02       1.238324E-10       1.980789E-02
                          A E R O S T A T I C   D A T A   R E C O V E R Y   O U T P U T   T A B L E
                                                  AEROELASTIC TRIM VARIABLES
                                                 TRIM VARIABLE    VALUE OF UX

                                                    ANGLEA        1.907433E-03
                                                    PITCH        -1.084202E-19
                                                    URDD3        -1.000000E+00
                                                    URDD5         0.000000E+00
                                                    ELEV          4.417495E-02
                                                    SIDES         1.959896E-09
                                                    YAW           3.874560E-09
                                                    ROLL          3.860787E-09
                                                    URDD2         0.000000E+00
                                                    URDD4         0.000000E+00
                                                    URDD6         1.615587E-27
                                                    AILERON       0.000000E+00
                                                    RUDDER        0.000000E+00
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Listing 7-24 Output for FSW Airplane with Bodies (Continued)

A E R O S T A T I C D A T A R E C O V E R Y O U T P U T T A B L E

MACH = 9.000000E-01 Q = 1.200000E+03

AERODYNAMIC GRID	LABEL	AERODYNAMIC PRES. COEFFICIENTS	AERODYNAMIC PRESSURES	AERODYNAMIC FORCES EXTERNAL ID	LABEL	NORMAL FORCES(T3)	MOMENTS(R2)
1	LS	2.197457E-01	2.636949E+02	1000	LS	3.296252E+02	2.060158E+02
2	LS	2.134067E-02	2.560880E+01	1001	LS	3.201165E+01	2.000728E+01
3	LS	8.235436E-03	9.882523E+00	1002	LS	1.235340E+01	7.720877E+00
4	LS	6.941908E-03	8.330289E+00	1003	LS	1.041307E+01	6.508169E+00
5	LS	2.061283E-01	2.473539E+02	1004	LS	1.545956E+03	9.662225E+02
6	LS	1.982115E-02	2.378538E+01	1005	LS	1.486581E+02	9.291129E+01
7	LS	7.704427E-03	9.245313E+00	1006	LS	5.778298E+01	3.611436E+01
8	LS	6.705724E-03	8.046868E+00	1007	LS	5.029273E+01	3.143295E+01
9	LS	-1.653892E-02	-1.984671E+01	1104	LS	-1.240419E+02	-7.752621E+01
10	LS	7.864603E-03	9.437523E+00	1105	LS	5.898452E+01	3.686533E+01
11	LS	4.503795E-03	5.404554E+00	1106	LS	3.377847E+01	2.111155E+01
12	LS	1.776906E-03	2.132287E+00	1107	LS	1.332679E+01	8.329247E+00
13	LS	8.997116E-02	1.079654E+02	1108	LS	6.747838E+02	4.217399E+02
14	LS	1.303863E-02	1.564635E+01	1109	LS	9.778970E+01	6.111857E+01
15	LS	6.372170E-03	7.646604E+00	1110	LS	4.779128E+01	2.986956E+01
16	LS	3.041159E-03	3.649391E+00	1111	LS	2.280869E+01	1.425543E+01
17	LS	9.469719E-02	1.136366E+02	1112	LS	7.102289E+02	4.438931E+02
18	LS	2.907472E-02	3.488967E+01	1113	LS	2.180604E+02	1.362878E+02
19	LS	9.546882E-03	1.145626E+01	1114	LS	7.160162E+01	4.475101E+01
20	LS	4.849496E-03	5.819396E+00	1115	LS	3.637122E+01	2.273201E+01
21	LS	8.148860E-02	9.778632E+01	1116	LS	6.232680E+02	3.895425E+02
22	LS	2.826109E-02	3.391330E+01	1117	LS	2.161557E+02	1.350973E+02
23	LS	1.321945E-02	1.586334E+01	1118	LS	1.011094E+02	6.319334E+01
24	LS	5.626781E-03	6.752137E+00	1119	LS	4.303660E+01	2.689787E+01
25	LS	6.758305E-02	8.109966E+01	1120	LS	5.169109E+02	3.230693E+02
26	LS	2.871564E-02	3.445876E+01	1121	LS	2.196324E+02	1.372702E+02
27	LS	1.489998E-02	1.787998E+01	1122	LS	1.139630E+02	7.122684E+01
28	LS	6.808581E-03	8.170298E+00	1123	LS	5.207563E+01	3.254727E+01
29	LS	5.297777E-02	6.357333E+01	1124	LS	4.052021E+02	2.532513E+02
30	LS	2.394363E-02	2.873236E+01	1125	LS	1.831336E+02	1.144585E+02
31	LS	1.422081E-02	1.706497E+01	1126	LS	1.087683E+02	6.798019E+01
32	LS	7.345882E-03	8.815059E+00	1127	LS	5.618520E+01	3.511575E+01
33	LS	3.528650E-02	4.234381E+01	1128	LS	2.698899E+02	1.686812E+02
34	LS	1.595349E-02	1.914419E+01	1129	LS	1.220207E+02	7.626295E+01
35	LS	1.036819E-02	1.244183E+01	1130	LS	7.930141E+01	4.956339E+01
36	LS	6.222871E-03	7.467445E+00	1131	LS	4.759581E+01	2.974738E+01
37	LS	2.061283E-01	2.473539E+02	2000	LS	1.545956E+03	9.662225E+02
38	LS	1.982118E-02	2.378542E+01	2001	LS	1.486583E+02	9.291142E+01
39	LS	7.704393E-03	9.245272E+00	2002	LS	5.778272E+01	3.611420E+01
40	LS	6.705716E-03	8.046859E+00	2003	LS	5.029267E+01	3.143291E+01
41	LS	2.197458E-01	2.636949E+02	2004	LS	3.296252E+02	2.060158E+02
42	LS	2.134071E-02	2.560886E+01	2005	LS	3.201171E+01	2.000732E+01
43	LS	8.235380E-03	9.882456E+00	2006	LS	1.235332E+01	7.720824E+00
44	LS	6.941923E-03	8.330308E+00	2007	LS	1.041309E+01	6.508184E+00
45	LS	3.528652E-02	4.234382E+01	2100	LS	2.698900E+02	1.686812E+02
46	LS	1.595351E-02	1.914421E+01	2101	LS	1.220209E+02	7.626305E+01
47	LS	1.036821E-02	1.244185E+01	2102	LS	7.930154E+01	4.956346E+01
48	LS	6.222877E-03	7.467453E+00	2103	LS	4.759586E+01	2.974741E+01
49	LS	5.297777E-02	6.357333E+01	2104	LS	4.052021E+02	2.532513E+02
50	LS	2.394365E-02	2.873237E+01	2105	LS	1.831337E+02	1.144585E+02
51	LS	1.422082E-02	1.706498E+01	2106	LS	1.087683E+02	6.798022E+01
52	LS	7.345878E-03	8.815054E+00	2107	LS	5.618517E+01	3.511573E+01
53	LS	6.758301E-02	8.109961E+01	2108	LS	5.169107E+02	3.230692E+02
54	LS	2.871561E-02	3.445874E+01	2109	LS	2.196322E+02	1.372701E+02
55	LS	1.489997E-02	1.787996E+01	2110	LS	1.139629E+02	7.122679E+01
56	LS	6.808588E-03	8.170306E+00	2111	LS	5.207570E+01	3.254731E+01
57	LS	8.148856E-02	9.778627E+01	2112	LS	6.232676E+02	3.895422E+02
58	LS	2.826110E-02	3.391332E+01	2113	LS	2.161558E+02	1.350974E+02
59	LS	1.321943E-02	1.586332E+01	2114	LS	1.011092E+02	6.319324E+01
60	LS	5.626791E-03	6.752150E+00	2115	LS	4.303668E+01	2.689792E+01
61	LS	9.469719E-02	1.136366E+02	2116	LS	7.102290E+02	4.438932E+02
62	LS	2.907470E-02	3.488964E+01	2117	LS	2.180603E+02	1.362877E+02
63	LS	9.546896E-03	1.145628E+01	2118	LS	7.160173E+01	4.475109E+01
64	LS	4.849524E-03	5.819428E+00	2119	LS	3.637143E+01	2.273214E+01
65	LS	8.997115E-02	1.079654E+02	2120	LS	6.747837E+02	4.217399E+02
66	LS	1.303864E-02	1.564636E+01	2121	LS	9.778978E+01	6.111862E+01
67	LS	6.372197E-03	7.646636E+00	2122	LS	4.779148E+01	2.986968E+01
68	LS	3.041142E-03	3.649371E+00	2123	LS	2.280857E+01	1.425535E+01
69	LS	-1.653893E-02	-1.984671E+01	2124	LS	-1.240420E+02	-7.752623E+01
70	LS	7.864612E-03	9.437534E+00	2125	LS	5.898459E+01	3.686537E+01
71	LS	4.503803E-03	5.404564E+00	2126	LS	3.377853E+01	2.111158E+01
72	LS	1.776905E-03	2.132286E+00	2127	LS	1.332679E+01	8.329241E+00
73	LS	-1.501252E-09	-1.801503E-06	3100	LS	-1.125939E-05	-7.037121E-06
74	LS	3.040361E-09	3.648433E-06	3101	LS	2.280271E-05	1.425170E-05
75	LS	2.393172E-09	2.871806E-06	3102	LS	1.794879E-05	1.121800E-05
76	LS	6.758486E-10	8.110183E-07	3103	LS	5.068864E-06	3.168040E-06
77	LS	-1.229602E-09	-1.475522E-06	3104	LS	-9.222016E-06	-5.763761E-06
78	LS	2.333110E-09	2.799732E-06	3105	LS	1.749833E-05	1.093646E-05
79	LS	3.938139E-09	4.725766E-06	3106	LS	2.953605E-05	1.846003E-05
80	LS	2.000437E-09	2.400525E-06	3107	LS	1.500328E-05	9.377050E-06
81	LS	1.249291E-09	1.499149E-06	3108	LS	9.369681E-06	5.856051E-06

Listing 7-24 Output for FSW Airplane with Bodies (Continued)

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     82    LS     -4.946589E-09     -5.935907E-06           3109   LS    -3.709942E-05     -2.318714E-05
     83    LS      6.511183E-09      7.813420E-06           3110   LS     4.883387E-05      3.052117E-05
     84    LS      4.136411E-09      4.963693E-06           3111   LS     3.102308E-05      1.938943E-05
     85    LS      1.349874E-02      1.619849E+01           3500   LS     4.049623E+01      2.531014E+01
     86    LS     -9.369577E-04     -1.124349E+00           3501   LS    -2.810873E+00     -1.756796E+00
     87    LS     -1.349874E-02     -1.619849E+01           3600   LS    -4.049623E+01     -2.531015E+01
     88    LS      9.369312E-04      1.124317E+00           3601   LS     2.810794E+00      1.756746E+00
     89    ZIB*    1.236755E-02      1.484106E+01           4000   YSB   -4.918611E-05      0.000000E+00
     90    ZIB*    2.627017E-02      3.152420E+01           4000   ZSB    1.874086E+01      0.000000E+00
     91    ZIB*    1.044219E-01      1.253063E+02           4001   YSB   -4.241869E-05      0.000000E+00
     92    ZIB*   -8.806521E-02     -1.056782E+02           4001   ZSB    3.483097E+01      0.000000E+00
     93    ZIB*    4.486084E-02      5.383301E+01           4002   YSB    3.101547E-05      0.000000E+00
     94    ZIB*   -1.320293E-01     -1.584351E+02           4002   ZSB    2.752336E+02      0.000000E+00
     95    ZIB*   -5.379935E-02     -6.455922E+01           4003   YSB    3.744381E-04      0.000000E+00
     96    ZIB*   -2.621078E-02     -3.145294E+01           4003   ZSB    7.336660E+02      0.000000E+00
     97    ZIB*   -4.027994E-03     -4.833593E+00           4004   YSB   -3.092265E-04      0.000000E+00
     98    ZIB*   -2.357787E-03     -2.829345E+00           4004   ZSB    2.818890E+02      0.000000E+00
     99    ZIB*    1.977045E-03      2.372454E+00           4005   YSB    1.870033E-04      0.000000E+00
    100    ZIB*    3.425907E-03      4.111089E+00           4005   ZSB    2.297896E+02      0.000000E+00
    101    ZIB*   -4.028021E-03     -4.833625E+00           4006   YSB   -6.144900E-05      0.000000E+00
    102    ZIB*   -2.357827E-03     -2.829393E+00           4006   ZSB    1.859019E+02      0.000000E+00
    103    ZIB*    1.976989E-03      2.372386E+00           4007   YSB   -7.878794E-05      0.000000E+00
    104    ZIB*    3.425851E-03      4.111021E+00           4007   ZSB    4.293805E+01      0.000000E+00
    105    YIB*   -2.791346E-09     -3.349615E-06           4510   YSB    5.453679E+00      0.000000E+00
    106    YIB*    6.776578E-09      8.131894E-06           4510   ZSB    1.407799E+00      0.000000E+00
    107    YIB*   -1.548653E-08     -1.858383E-05           4511   YSB    1.715474E+01      0.000000E+00
    108    YIB*    5.712243E-07      6.854691E-04           4511   ZSB    5.035899E+00      0.000000E+00
    109    YIB*    1.987807E-08      2.385368E-05           4512   YSB    2.048823E+00      0.000000E+00
    110    YIB*    3.456430E-07      4.147716E-04           4512   ZSB    3.964195E+00      0.000000E+00
    111    YIB*    1.699642E-07      2.039571E-04           4513   YSB    1.437641E+00      0.000000E+00
    112    YIB*   -1.063246E-07     -1.275895E-04           4513   ZSB   -7.397157E+00      0.000000E+00
    113    YIB*   -1.948816E-02     -2.338579E+01           4610   YSB   -5.453685E+00      0.000000E+00
    114    YIB*   -2.471328E-02     -2.965594E+01           4610   ZSB    1.407766E+00      0.000000E+00
    115    YIB*   -2.343771E-02     -2.812525E+01           4611   YSB   -1.715474E+01      0.000000E+00
    116    YIB*   -2.363333E-02     -2.836000E+01           4611   ZSB    5.035889E+00      0.000000E+00
    117    YIB*    1.948814E-02      2.338577E+01           4612   YSB   -2.048852E+00      0.000000E+00
    118    YIB*    2.471327E-02      2.965592E+01           4612   ZSB    3.964183E+00      0.000000E+00
    119    YIB*    2.343768E-02      2.812522E+01           4613   YSB   -1.437648E+00      0.000000E+00
    120    YIB*    2.363331E-02      2.835998E+01           4613   ZSB   -7.397151E+00      0.000000E+00
    121    ZSB*    4.610739E-03      5.532887E+00
    122    ZSB*    3.166118E-02      3.799342E+01
    123    ZSB*    6.076573E-02      7.291888E+01
    124    ZSB*    8.306995E-02      9.968394E+01
    125    ZSB*    1.062085E-01      1.274501E+02
    126    ZSB*    1.704039E-01      2.044846E+02
    127    ZSB*    2.349322E-01      2.819186E+02
    128    ZSB*    2.380018E-01      2.856022E+02
    129    ZSB*    3.587926E-03      4.305511E+00
    130    ZSB*    1.435171E-02      1.722205E+01
    131    ZSB*    1.435171E-02      1.722205E+01
    132    ZSB*    3.587926E-03      4.305511E+00
    133    ZSB*    3.587923E-03      4.305508E+00
    134    ZSB*    1.435169E-02      1.722203E+01
    135    ZSB*    1.435169E-02      1.722203E+01
    136    ZSB*    3.587923E-03      4.305508E+00
    137    YSB*   -2.082073E-08     -2.498488E-05
    138    YSB*   -1.153673E-07     -1.384408E-04
    139    YSB*   -1.535662E-07     -1.842794E-04
    140    YSB*   -1.229189E-07     -1.475027E-04
    141    YSB*   -7.420095E-08     -8.904114E-05
    142    YSB*   -3.289821E-08     -3.947785E-05
    143    YSB*    3.499495E-08      4.199394E-05
    144    YSB*    1.110134E-07      1.332161E-04
    145    YSB*   -1.428826E-05     -1.714591E-02
    146    YSB*   -5.715151E-05     -6.858181E-02
    147    YSB*   -5.714999E-05     -6.857999E-02
    148    YSB*   -1.428712E-05     -1.714454E-02
    149    YSB*    1.428725E-05      1.714470E-02
    150    YSB*    5.715052E-05      6.858063E-02
    151    YSB*    5.715204E-05      6.858245E-02
    152    YSB*    1.428839E-05      1.714607E-02

*** LABEL NOTATIONS:  LS = LIFTING SURFACE,   ZIB = Z INTERFERENCE BODY ELEMENT,   ZSB = Z SLENDER BODY ELEMENT,
                                              YIB = Y INTERFERENCE BODY ELEMENT,   YSB = Y SLENDER BODY ELEMENT.

* NOTE THAT, FOR BODY ELEMENTS, PRESSURES ARE NOT AVAILABLE.   THE VALUES PRINTED REPRESENT DOUBLET STRENGTHS.
  PLEASE SEE THE HANDBOOK FOR AEROELASTICITY.
```

Listing 7-24 Output for FSW Airplane with Bodies (Continued)

```
                                             D I S P L A C E M E N T   V E C T O R

      POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
             88      G      0.0            0.0            2.066694E-04  -5.459292E-05   1.158922E-04   0.0
             89      G      0.0            0.0            4.933557E-05  -4.350332E-05   6.648706E-05   0.0
             90      G      0.0            0.0            0.0            0.0            0.0            0.0
             91      G      0.0            0.0            4.933557E-05   4.350332E-05   6.648705E-05   0.0
             92      G      0.0            0.0            2.066694E-04   5.459292E-05   1.158922E-04   0.0
             97      G      0.0           -1.627291E-10  -7.360668E-03   0.0           -7.187539E-04   1.863641E-11
             98      G      0.0           -1.447897E-11  -1.161003E-03   0.0           -4.223916E-04   7.202234E-12
             99      G      4.896077E-20  -3.723963E-13  -9.832990E-04   1.888854E-12   3.988778E-04   1.261683E-12
            100      G      1.600101E-19   1.287807E-10  -1.012783E-02   5.666561E-12   1.530052E-03   3.072896E-11
            110      G     -2.837356E-05  -1.786642E-05  -2.610124E-03   7.465275E-04   2.258455E-03   1.107073E-05
            111      G     -2.837356E-05  -4.554326E-05   3.036012E-03   7.465275E-04   2.258455E-03   1.107073E-05
            112      G     -2.837356E-05   9.810412E-06  -8.256260E-03   7.465275E-04   2.258455E-03   1.107073E-05
            115      G     -1.040624E-04  -6.305047E-05   9.420018E-03   1.143538E-03   2.660419E-03   1.892614E-05
            120      G      2.517411E-03  -1.376084E-03   2.355001E-02   1.248269E-03   2.905261E-03   4.922319E-05
            121      G      2.517411E-03  -1.499142E-03   3.081316E-02   1.248269E-03   2.905261E-03   4.922319E-05
            122      G      2.517411E-03  -1.253026E-03   1.628686E-02   1.248269E-03   2.905261E-03   4.922319E-05
            150      G     -4.094846E-03   1.561312E-03   2.272429E-02   1.143553E-03   2.660969E-03   1.815946E-05
            151      G     -4.094846E-03   1.652271E-03   9.420020E-03   1.143553E-03   2.660625E-03   1.825637E-05
            210      G     -2.837325E-05   1.786650E-05  -2.610124E-03  -7.465275E-04   2.258454E-03  -1.107067E-05
            211      G     -2.837325E-05   4.554318E-05   3.036012E-03  -7.465275E-04   2.258454E-03  -1.107067E-05
            212      G     -2.837325E-05  -9.810176E-06  -8.256260E-03  -7.465275E-04   2.258454E-03  -1.107067E-05
            215      G     -1.040618E-04   6.305036E-05   9.420017E-03  -1.143537E-03   2.660419E-03  -1.892608E-05
            220      G      2.517412E-03   1.376084E-03   2.355001E-02  -1.248269E-03   2.905261E-03  -4.922312E-05
            221      G      2.517412E-03   1.499142E-03   3.081316E-02  -1.248269E-03   2.905261E-03  -4.922312E-05
            222      G      2.517412E-03   1.253026E-03   1.628686E-02  -1.248269E-03   2.905261E-03  -4.922312E-05
            250      G     -4.094845E-03  -1.561312E-03   2.272429E-02  -1.143553E-03   2.660969E-03  -1.815940E-05
            251      G     -4.094845E-03  -1.652271E-03   9.420019E-03  -1.143553E-03   2.660625E-03  -1.825630E-05
            310      G      7.658370E-03   1.936182E-10  -1.454966E-02   7.282316E-12   1.532231E-03   3.598105E-11
            311      G      7.658370E-03   1.036656E-10  -1.071908E-02   7.282316E-12   1.532231E-03   3.598105E-11
            312      G      7.658370E-03   2.835708E-10  -1.838024E-02   7.282316E-12   1.532231E-03   3.598105E-11
            890      G      0.0            0.0            4.933557E-05  -4.350332E-05   6.648706E-05   0.0
            910      G      0.0            0.0            4.933557E-05   4.350332E-05   6.648705E-05   0.0

                                   F O R C E S   I N   B A R   E L E M E N T S         ( C B A R )
    ELEMENT         BEND-MOMENT END-A            BEND-MOMENT END-B                - SHEAR -              AXIAL
      ID.         PLANE 1       PLANE 2        PLANE 1       PLANE 2        PLANE 1       PLANE 2        FORCE         TORQUE
        89    -7.741117E+02  0.0            2.622377E+03  0.0           -1.132163E+03  0.0            0.0           -4.117094E+03
        90     3.250819E+03  0.0            7.625005E+03  0.0           -2.187093E+03  0.0            0.0           -8.310884E+03
        91     7.625004E+03  0.0            3.250818E+03  0.0            2.187093E+03  0.0            0.0            8.310882E+03
        92     2.622377E+03  0.0           -7.741116E+02  0.0            1.132163E+03  0.0            0.0            4.117093E+03
       100    -3.822030E+04  2.566290E-04  -4.155522E+04 -4.746479E-04   6.669843E+02  1.462554E-04   5.640281E-11   2.039962E-04
       101    -5.456968E-12 -2.241588E-17  -2.963621E+04  9.879128E-04   2.963621E+03 -9.879128E-05   0.0            0.0
       102    -2.963621E+04  9.879128E-04  -5.484206E+04  2.566332E-04   5.041170E+03  1.462559E-04   0.0            0.0
       103    -4.155522E+04 -4.746479E-04  -7.156216E+04 -2.071325E-03   3.000694E+03  1.596677E-04   6.396444E-11   2.039962E-04
       110     5.200714E+04 -6.324351E+03   3.552312E+04 -4.720463E+03   2.855118E+03 -2.778015E+02  -4.811666E+02   1.115231E+04
       115     3.282450E+04 -4.720463E+03   1.435679E+04 -3.116575E+03   3.198701E+03 -2.778016E+02  -4.811666E+02   6.478144E+03
       120     1.428939E+04 -2.075387E+03   3.896671E+03 -4.824830E+02   1.773664E+03 -2.718516E+02  -1.706641E+02   6.933296E+03
       150     1.455192E-11  2.910383E-11   3.435822E+01 -1.116298E+02  -6.871643E+00  2.232595E+01   2.910383E-11  -2.728484E-12
       151    -3.435822E+01 -5.820766E-11  -3.435822E+01  5.798500E+01  -8.731149E-11 -3.865667E+01  -3.010736E+00   1.116298E+02
       210     5.200714E+04  6.324349E+03   3.552311E+04  4.720462E+03   2.855118E+03  2.778014E+02  -4.811665E+02  -1.115231E+04
       215     3.282450E+04  4.720462E+03   1.435679E+04  3.116574E+03   3.198700E+03  2.778015E+02  -4.811664E+02  -6.478143E+03
       220     1.428939E+04  2.075387E+03   3.896670E+03  4.824830E+02   1.773664E+03  2.718516E+02  -1.706641E+02  -6.933294E+03
       250    -2.910383E-11  2.910383E-11   3.435807E+01  1.116297E+02  -6.871614E+00 -2.232594E+01   0.0            5.456968E-12
       251    -3.435807E+01  1.746230E-10  -3.435807E+01 -5.798510E+01  -5.820766E-11  3.865673E+01  -3.010688E+00  -1.116297E+02
       310    -2.386749E+02 -1.089980E-03   4.999999E+01 -1.339079E-04  -4.999997E+01 -1.655967E-04  -8.660255E+01   2.319354E-04
```

Listing 7-24 Output for FSW Airplane with Bodies (Continued)

```
                                S T R E S S E S   I N   B A R   E L E M E N T S         ( C B A R )
  ELEMENT          SA1            SA2            SA3            SA4           AXIAL          SA-MAX         SA-MIN     M.S.-T
    ID.            SB1            SB2            SB3            SB4           STRESS         SB-MAX         SB-MIN     M.S.-C
0      89    2.229443E+03   2.229443E+03  -2.229443E+03  -2.229443E+03   0.0            2.229443E+03  -2.229443E+03
            -7.552450E+03  -7.552450E+03   7.552450E+03   7.552450E+03                  7.552450E+03  -7.552450E+03
0      90   -9.362364E+03  -9.362364E+03   9.362364E+03   9.362364E+03   0.0            9.362364E+03  -9.362364E+03
            -2.196003E+04  -2.196003E+04   2.196003E+04   2.196003E+04                  2.196003E+04  -2.196003E+04
0      91   -2.196003E+04  -2.196003E+04   2.196003E+04   2.196003E+04   0.0            2.196003E+04  -2.196003E+04
            -9.362363E+03  -9.362363E+03   9.362363E+03   9.362363E+03                  9.362363E+03  -9.362363E+03
0      92   -7.552450E+03  -7.552450E+03   7.552450E+03   7.552450E+03   0.0            7.552450E+03  -7.552450E+03
             2.229443E+03   2.229443E+03  -2.229443E+03  -2.229443E+03                  2.229443E+03  -2.229443E+03
0     100    1.100745E+05   1.100745E+05  -1.100745E+05  -1.100745E+05   1.410070E-11   1.100745E+05  -1.100745E+05
             1.196791E+05   1.196791E+05  -1.196791E+05  -1.196791E+05                  1.196791E+05  -1.196791E+05
0     101    1.571615E-11   1.571600E-11  -1.571600E-11  -1.571615E-11   0.0            1.571615E-11  -1.571615E-11
             8.535234E+04   8.535234E+04  -8.535234E+04  -8.535234E+04                  8.535234E+04  -8.535234E+04
0     102    8.535234E+04   8.535234E+04  -8.535234E+04  -8.535234E+04   0.0            8.535234E+04  -8.535234E+04
             1.579452E+05   1.579452E+05  -1.579452E+05  -1.579452E+05                  1.579452E+05  -1.579452E+05
0     103    1.196791E+05   1.196791E+05  -1.196791E+05  -1.196791E+05   1.599111E-11   1.196791E+05  -1.196791E+05
             2.060992E+05   2.060991E+05  -2.060991E+05  -2.060992E+05                  2.060992E+05  -2.060992E+05
0     110   -1.402941E+05  -1.592672E+05   1.592672E+05   1.402941E+05  -3.207777E+02   1.589464E+05  -1.595880E+05
            -9.522595E+04  -1.093873E+05   1.093873E+05   9.522595E+04                  1.090666E+05  -1.097081E+05
0     115   -8.745391E+04  -1.016153E+05   1.016153E+05   8.745391E+04  -3.207777E+02   1.012945E+05  -1.019361E+05
            -3.667271E+04  -4.602244E+04   4.602244E+04   3.667271E+04                  4.570166E+04  -4.634322E+04
0     120   -3.804039E+04  -4.426656E+04   4.426656E+04   3.804039E+04  -1.137760E+02   4.415278E+04  -4.438034E+04
            -1.049869E+04  -1.194614E+04   1.194614E+04   1.049869E+04                  1.183237E+04  -1.205992E+04
0     150   -8.556529E-11   1.746203E-12  -1.746203E-12   8.556529E-11   1.940255E-11   1.049678E-10  -6.616274E-11
             6.849292E+01  -2.663964E+02   2.663964E+02  -6.849292E+01                  2.663964E+02  -2.663964E+02
0     151    9.895172E+01   9.895172E+01  -9.895172E+01  -9.895172E+01  -2.007157E+00   9.694456E+01  -1.009589E+02
             1.197422E+01   1.859292E+02  -1.859292E+02  -1.197422E+01                  1.839221E+02  -1.879364E+02
0     210   -1.592672E+05  -1.402941E+05   1.402941E+05   1.592672E+05  -3.207776E+02   1.589464E+05  -1.595880E+05
            -1.093873E+05  -9.522594E+04   9.522594E+04   1.093873E+05                  1.090665E+05  -1.097081E+05
0     215   -1.016153E+05  -8.745391E+04   8.745391E+04   1.016153E+05  -3.207776E+02   1.012945E+05  -1.019361E+05
            -4.602245E+04  -3.667272E+04   3.667272E+04   4.602245E+04                  4.570167E+04  -4.634322E+04
0     220   -4.426655E+04  -3.804039E+04   3.804039E+04   4.426655E+04  -1.137760E+02   4.415278E+04  -4.438033E+04
            -1.194614E+04  -1.049869E+04   1.049869E+04   1.194614E+04                  1.183236E+04  -1.205992E+04
0     250    4.016334E-11   1.274748E-10  -1.274748E-10  -4.016334E-11   0.0            1.274748E-10  -1.274748E-10
            -2.663958E+02   6.849322E+01  -6.849322E+01   2.663958E+02                  2.663958E+02  -2.663958E+02
0     251    9.895129E+01   9.895129E+01  -9.895129E+01  -9.895129E+01  -2.007125E+00   9.694417E+01  -1.009584E+02
             1.859290E+02   1.197364E+01  -1.197364E+01  -1.859290E+02                  1.839218E+02  -1.879361E+02
0     310    6.873859E+02   6.873826E+02  -6.873826E+02  -6.873859E+02  -5.773503E+01   6.296508E+02  -7.451209E+02
            -1.439999E+02  -1.440003E+02   1.440003E+02   1.439999E+02                  8.626524E+01  -2.017353E+02
```

Unit Solution for Loadings of the FSW Airplane

The preceding examples of static aeroelastic analysis all result in trimmed solutions. For some design studies, it may be desirable to separate the trimmed loading into the unit solutions generated by each trim variable. These solutions are available from MSC Nastran, but require a DMAP alter to efficiently provide the results. The solution is illustrated using the familiar forward swept wing example of example HA144a. Six dummy subcases are available to produce the six unit solutions for intercept, four aestat entries and the aesurf for the elevator. The alter produces a single set of stability derivatives and then provides unit solutions inside the subcase loop so that the TRIM case control and bulk data entry are ignored. Listing 7-25 provides the input file while Listing 7-26 shows selected output. Only results for the first two subcases are shown in the listing in order to limit its size.

Listing 7-25 Input File for Unit Solutions of Example HA144GB

```
ID MSC, HA144GB $
    $$$$$$$$  HANDBOOK FOR AEROELASTIC ANALYSIS EXAMPLE HA144GB     $$$$$$$$
    $                                                                      $
    $       MODEL DESCRIPTION        30 DEG FWD SWEPT WING W/CANARD        $
    $                                BEAM MODEL WITH DUMBBELL MASSES       $
    $                                                                      $
    $       SOLUTION                 SYMMETRIC IN-FLIGHT STATIC STABILITY  $
    $                                ANALYSIS USING DOUBLET-LATTICE        $
    $                                METHOD AERODYNAMICS AT MACH NO. 0.9   $
    $                                                                      $
    $$$$$$$$                                                        $$$$$$$$
    TIME 5 $ CPU TIME IN MINUTES
    DIAG 8 $
    SOL 144 $ STATIC AERO
    COMPILE AESTATRS
    $
    $ UNIT SOLUTION ALTER
    $
    $ DO NOT CALL THE STANDARD SOLUTION
    ALTER 'ASG *CASEA','ASG *CASEA'(1,1)
    $ CALL SDP ONLY ON THE FIRST PASS
    $ (WOULDN'T HURT TO CALL IT AGAIN AND AGAIN, BUT
    $ THE OUTPUT WON'T CHANGE.
    IF ( ICASE = 1 ) THEN $
    PURGEX /UX,,,,/ALWAYS $
    $
    ALTER 'SDP *CASEA'(2)
    ENDIF $
    $
    $ GRAB THE ICASE'TH COLUMN OF THE NX LOCAL SLOPE INTERPOLATION
    $ AND COMPUTE THE CORRESPONDING UX FOR DATA RECOVERY


$
    MATMOD UXDIFV,,,,,/UXIFVT,/1/ICASE $ GET THE RIGHT COLUMN
    EQUIVX UXIFVT/UXIFV/ALWAYS $
    MPYAD AEDBUXV,UXIFV,/UX $ THE CURRENT UX VECTOR
    ALTER 'ASDR *CASEA',''
    $ MAKE SPECIALIZED CALL TO ASDR FOR UNIT SOLUTIONS
    ASDR     CASEA,,CONTROL,
             FFAJ,ACPT,PAK,AEUSET,AEBGPDT,AECOMP,
             MONITOR,MPSR,MPSER,MPSIR,MPSRPS,MPSERPS,MPAERPS,
             AEMONPT,MPAR,MPAER,AERO,CSTMA/OTRIMV,OAEF,OAEP/
             MACHNO/Q/AECONFIG/SYMXY/SYMXZ/ICASE $
    ALTER 'AECSV *CASEA,UXDAT',''
    $ PURGE UXDAT IN CALL TO AECSV
                   AECSV    CASEA,,CONTROL,OGPWG,
                            MONITOR,MPSR,MPSER,MPSIR,MPSRPS,MPSERPS,
                            MP2SLAB,MP2SER,
                            MONT3,MP3ER,
                            DMONPTS,MPSDISP,
                            AEMONPT,MPAR,MPAER,
                            DMONPTA,MPADISP,STBDER,UXREF/
                            CSVFILE,SDFILE,SDDSAV/
                            MACHNO/Q/LDSUM/SDCSV $
    $ NO UXDAT TO APPEND OF EQUIV
    ALTER 'APPEND *UXDAT.*AUXDAT',''
    ALTER 'EQUIVX *AUXDAT.*AUXTAB',''
    $
    $ END OF ALTER
    $
    ENDALTER
    CEND
```

Listing 7-25 Input File for Unit Solutions of Example HA144GB (Continued)

```
1     EXAMPLE HA144GB: 30 DEG FWD SWEPT WING WITH CANARD     HA144GB           JUNE  11, 2019  MSC Nastran  6/10/19   PAGE     4
       STABILITY DERIVATIVES AND UNIT SOLUTIONS
0      HALF-SPAN MODEL, STATIC SYMMETRIC LOADING
0                                  C A S E    C O N T R O L    E C H O
                 COMMAND
                 COUNT
                  1      TITLE = EXAMPLE HA144GB: 30 DEG FWD SWEPT WING WITH CANARD     HA144GB
                  2      SUBTI = STABILITY DERIVATIVES AND UNIT SOLUTIONS
                  3      LABEL = HALF-SPAN MODEL, STATIC SYMMETRIC LOADING
                  4        ECHO    = BOTH
                  5        SPC     = 1   $ SYMMETRIC CONSTRAINTS
                  6        DISP    = ALL $ PRINT ALL DISPLACEMENTS
                  7        STRESS  = ALL $ PRINT ALL STRESSES
                  8        FORCE   = ALL $ PRINT ALL FORCES
                  9        AEROF   = ALL $ PRINT ALL AERODYNAMIC FORCES
                 10        APRES   = ALL $ PRINT ALL AERODYNAMIC PRESSURES
                 11      SUBCASE 1
                 12        TRIM = 1      $ INTERCEPT SOLUTION
                 13      SUBCASE 2
                 14        TRIM = 1      $ ANGLEA SOLUTION
                 15      SUBCASE 3
                 16        TRIM = 1      $ PITCH RATE SOLUTION
                 17      SUBCASE 4
                 18        TRIM = 1      $ URDD3 SOLUTION
                 19      SUBCASE 5
                 20        TRIM = 1      $ URDD5 SOLUTION
                 21      SUBCASE 6
                 22        TRIM = 1      $ ELEV SOLUTION
                 23      BEGIN BULK
                                          S O R T E D   B U L K   D A T A   E C H O
                 ENTRY
                 COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                     1-        AELIST  1000    1000    THRU    1007
                     2-        AEROS   1       100     10.     40.     200.    1
                     3-        AESTAT  501     ANGLEA
                     4-        AESTAT  502     PITCH
                     5-        AESTAT  503     URDD3
                     6-        AESTAT  504     URDD5
                     7-        AESURF  505     ELEV    1       1000
                     8-        CAERO1  1000    1000            2       4                       1       +
                     9-        +       10.     0.      0.      10.     10.     5.      0.      10.
                    10-        CAERO1  1100    1000            8       4                       1       +
                    11-        +       25.     0.      0.      10.     13.4529920.     0.      10.
                    12-        CBAR    100     100     90      99      0.      0.      1.
                    13-        CBAR    101     100     97      98      0.      0.      1.
                    14-        CBAR    102     100     98      90      0.      0.      1.
                    15-        CBAR    103     100     99      100     0.      0.      1.
                    16-        CBAR    110     101     100     110     0.      0.      1.
                    17-        CBAR    120     101     110     120     0.      0.      1.
                    18-        CONM2   97      97      0       1500.
                    19-        CONM2   98      98      0       1500.
                    20-        CONM2   99      99      0       1500.
                    21-        CONM2   100     100     0       1500.
                    22-        CONM2   111     111     0       600.
                    23-        CONM2   112     112     0       400.
                    24-        CONM2   121     121     0       600.
                    25-        CONM2   122     122     0       400.
                    26-        CORD2R  1       0       12.5    0.      0.      12.5    0.      10.     +
                    27-        +       20.     0.      0.
                    28-        CORD2R  2       0       30.     0.      0.      30.     0.      10.     +
                    29-        +       38.660255.      0.
                    30-        CORD2R  100     0       15.     0.      0.      15.     0.      -10.    +
                    31-        +       0.      0.      0.
                    32-        DMI     W2GJ    0       2       1       0               40      1
                    33-        DMI     W2GJ    1       9       .0017453THRU    40
                    34-        DMI     WKK     0       3       1       0               80      1
                    35-        DMI     WKK     1       1       1.0     THRU    80
                    36-        GRID    90              15.     0.      0.
                    37-        GRID    97              0.      0.      0.
                    38-        GRID    98              10.     0.      0.
                    39-        GRID    99              20.     0.      0.
                    40-        GRID    100             30.     0.      0.
                    41-        GRID    110             27.113255.      0.
                    42-        GRID    111             24.613255.      0.
                    43-        GRID    112             29.613255.      0.
                    44-        GRID    120             21.3397515.     0.
                    45-        GRID    121             18.8397515.     0.
                    46-        GRID    122             23.8397515.     0.
                    47-        MAT1    1       1.44E+095.4E+08
                    48-        PAERO1  1000
                    49-        PARAM   AUNITS  .031081
                    50-        PARAM   GRDPNT  90
```

Listing 7-25 Input File for Unit Solutions of Example HA144GB (Continued)

```
          PARAM   WTMASS  .031081
          PBAR    100     1       2.      .173611 .15     .5                      +
          +       1.      1.      1.      -1.     -1.     1.      -1.     -1.     +
          +                       0.
          PBAR    101     1       1.5     .173611 2.      .462963                 +
          +       .5      3.      .5      -3.     -.5     3.      -.5     -3.     +
          +                       0.
          RBAR    111     110     111     123456
          RBAR    112     110     112     123456
          RBAR    121     120     121     123456
          RBAR    122     120     122     123456
          SET1    1000    98      99
          SET1    1100    99      100     111     112     121     122
          SPC1    1       246     97      98      99      100
          SPC1    1       1246    90
          SPLINE2 1501    1000    1000    1007    1000    0.      1.      1       +
          +       1.      -1.
          SPLINE2 1601    1100    1100    1131    1100    0.      1.      2       +
          +       -1.     -1.
          SUPORT  90      35
          TRIM    1       .9      1200.   ANGLEA  0.      PITCH   0.              +
          +       URDD3   0.      URDD5   0.      ELEV    0.
          ENDDATA
    TOTAL COUNT= 73
```

Listing 7-26 Output for Unit Solutions of Example HA144GB

```
  N O N - D I M E N S I O N A L   S T A B I L I T Y   A N D   C O N T R O L   D E R I V A T I V E   C O E F F I C I E N T S

                      CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
                                      MACH = 9.0000E-01                    Q = 1.2000E+03
                      CHORD = 1.0000E+01           SPAN = 4.0000E+01           AREA = 2.0000E+02


             TRANSFORMATION FROM BASIC TO REFERENCE COORDINATES:

           { X }         [ -1.0000    0.0000    0.0000  ]  { X }          { 1.5000E+01 }
           { Y }    =    [  0.0000    1.0000    0.0000  ]  { Y }      +   { 0.0000E+00 }
           { Z }REF      [  0.0000    0.0000   -1.0000  ]  { Z }BAS       { 0.0000E+00 }


 CONTROLLER STATE: INTERCEPT ONLY, ALL CONTROLLERS ARE ZERO

  TRIM VARIABLE   COEFFICIENT             RIGID                            ELASTIC                              INERTIAL
                               UNSPLINED         SPLINED        RESTRAINED      UNRESTRAINED       RESTRAINED      UNRESTRAINED

  REF. COEFF.      CX        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                   CY        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                   CZ       -8.420786E-03   -8.420786E-03   -1.033208E-02   -1.265279E-02     0.000000E+00   -1.265279E-02
                   CMX       0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                   CMY      -6.008128E-03   -6.008128E-03   -7.073892E-03   -8.678376E-03     0.000000E+00   -8.678376E-03
                   CMZ       0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00

  ANGLEA           CX        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                   CY        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                   CZ       -5.070975E+00   -5.070975E+00   -6.462927E+00   -7.771567E+00     0.000000E+00   -7.771567E+00
                   CMX       0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                   CMY      -2.870931E+00   -2.870931E+00   -3.667061E+00   -4.576803E+00     0.000000E+00   -4.576803E+00
                   CMZ       0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00

  PITCH            CX        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                   CY        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                   CZ       -1.207429E+01   -1.207429E+01   -1.285577E+01   -1.610021E+01     0.000000E+00   -1.610021E+01
                   CMX       0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                   CMY      -9.953998E+00   -9.953998E+00   -1.027399E+01   -1.249935E+01     0.000000E+00   -1.249935E+01
                   CMZ       0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00

  URDD3            CX        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                   CY        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                   CZ        0.000000E+00    0.000000E+00    3.634421E-03    0.000000E+00     3.333333E-02    0.000000E+00
                   CMX       0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                   CMY       0.000000E+00    0.000000E+00    2.623634E-03    0.000000E+00     7.272083E-03    0.000000E+00
                   CMZ       0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
```

Listing 7-26 Output for Unit Solutions of Example HA144GB (Continued)

```
1     EXAMPLE HA144GB: 30 DEG FWD SWEPT WING WITH CANARD     HA144GB           JUNE  11, 2019  MSC Nastran  6/10/19   PAGE    21
       STABILITY DERIVATIVES AND UNIT SOLUTIONS
0      HALF-SPAN MODEL, STATIC SYMMETRIC LOADING                                                               SUBCASE 1

   TRIM VARIABLE   COEFFICIENT             RIGID                        ELASTIC                             INERTIAL
                              UNSPLINED        SPLINED       RESTRAINED      UNRESTRAINED     RESTRAINED      UNRESTRAINED

   URDD5            CX        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                    CY        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                    CZ        0.000000E+00    0.000000E+00    7.244891E-02    0.000000E+00    7.272083E-02    0.000000E+00
                    CMX       0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                    CMY       0.000000E+00    0.000000E+00    4.702158E-02    0.000000E+00    3.879043E-01    0.000000E+00
                    CMZ       0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00

   ELEV             CX        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                    CY        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                    CZ       -2.461394E-01   -2.461394E-01   -5.429842E-01   -5.219328E-01    0.000000E+00   -5.219328E-01
                    CMX       0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                    CMY       5.715301E-01    5.715301E-01    3.860486E-01    3.956233E-01    0.000000E+00    3.956233E-01
                    CMZ       0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                                                         AEROELASTIC TRIM VARIABLES

                                         ID      LABEL                 TYPE        TRIM STATUS      VALUE OF UX

                                                 INTERCEPT          RIGID BODY          FIXED       1.000000E+00
                                        501      ANGLEA             RIGID BODY          FIXED       0.000000E+00  RADIANS
                                        502      PITCH              RIGID BODY          FIXED       0.000000E+00  NONDIMEN. RATE
                                        503      URDD3              RIGID BODY          FIXED       0.000000E+00  LOAD FACTOR
                                        504      URDD5              RIGID BODY          FIXED       0.000000E+00  RAD/S/S PER G
                                        505      ELEV          CONTROL SURFACE          FIXED       0.000000E+00  RADIANS
                                                        AERODYNAMIC PRESSURES ON THE AERODYNAMIC ELEMENTS

                                                       AERODYNAMIC PRES.       AERODYNAMIC
                                                GRID   LABEL          COEFFICIENTS           PRESSURES
                                                  1     LS            8.645255E-04         1.037431E+00
                                                  2     LS            9.342589E-04         1.121111E+00
                                                  3     LS            1.551323E-03         1.861588E+00
                                                  4     LS            2.427775E-03         2.913330E+00
                                                  5     LS            6.718649E-04         8.062379E-01
                                                  6     LS            7.300185E-04         8.760222E-01
                                                  7     LS            1.255685E-03         1.506821E+00
                                                  8     LS            2.173061E-03         2.607673E+00
                                                  9     LS            3.140396E-02         3.768475E+01
                                                 10     LS            8.190623E-03         9.828747E+00
                                                 11     LS            3.100010E-03         3.720012E+00
                                                 12     LS            1.090941E-03         1.309129E+00
                                                 13     LS            2.808249E-02         3.369899E+01
                                                 14     LS            1.036210E-02         1.243452E+01
                                                 15     LS            4.421210E-03         5.305452E+00
                                                 16     LS            1.355179E-03         1.626215E+00
                                                 17     LS            2.980389E-02         3.576467E+01
                                                 18     LS            1.167770E-02         1.401324E+01
                                                 19     LS            5.542692E-03         6.651230E+00
                                                 20     LS            1.428172E-03         1.713807E+00
                                                 21     LS            2.644348E-02         3.173218E+01
                                                 22     LS            1.156805E-02         1.388166E+01
                                                 23     LS            6.411157E-03         7.693388E+00
                                                 24     LS            2.861868E-03         3.434241E+00
                                                 25     LS            2.339144E-02         2.806973E+01
                                                 26     LS            1.060380E-02         1.272456E+01
                                                 27     LS            6.417693E-03         7.701232E+00
                                                 28     LS            3.311540E-03         3.973848E+00
                                                 29     LS            2.021148E-02         2.425377E+01
                                                 30     LS            9.227424E-03         1.107291E+01
                                                 31     LS            5.903499E-03         7.084199E+00
                                                 32     LS            3.336836E-03         4.004203E+00
                                                 33     LS            1.644886E-02         1.973863E+01
                                                 34     LS            7.445402E-03         8.934482E+00
                                                 35     LS            4.959066E-03         5.950879E+00
                                                 36     LS            3.048319E-03         3.657983E+00
                                                 37     LS            1.131609E-02         1.357930E+01
                                                 38     LS            4.946158E-03         5.935389E+00
                                                 39     LS            3.392895E-03         4.071474E+00
                                                 40     LS            2.313883E-03         2.776660E+00
                *** LABEL NOTATIONS:  LS = LIFTING SURFACE,   ZIB = Z INTERFERENCE BODY ELEMENT,  ZSB = Z SLENDER BODY ELEMENT,
                                                              YIB = Y INTERFERENCE BODY ELEMENT,  YSB = Y SLENDER BODY ELEMENT.

                                   A E R O S T A T I C   D A T A   R E C O V E R Y   O U T P U T   T A B L E S
                            CONFIGURATION = AEROSG2D      XY-SYMMETRY = ASYMMETRIC      XZ-SYMMETRY = SYMMETRIC
                                              MACH = 9.000000E-01                Q = 1.200000E+03
                            CHORD = 1.0000E+01           SPAN = 4.0000E+01            AREA = 2.0000E+02
```

Listing 7-26 Output for Unit Solutions of Example HA144GB (Continued)

```
                                        AERODYNAMIC FORCES ON THE AERODYNAMIC ELEMENTS

GROUP  GRID ID  LABEL        T1              T2              T3              R1              R2              R3
   1     1000    LS    0.000000E+00    0.000000E+00    6.483941E+00    0.000000E+00    4.052463E+00    0.000000E+00
   1     1001    LS    0.000000E+00    0.000000E+00    7.006942E+00    0.000000E+00    4.379339E+00    0.000000E+00
   1     1002    LS    0.000000E+00    0.000000E+00    1.163492E+01    0.000000E+00    7.271827E+00    0.000000E+00
   1     1003    LS    0.000000E+00    0.000000E+00    1.820831E+01    0.000000E+00    1.138020E+01    0.000000E+00
   1     1004    LS    0.000000E+00    0.000000E+00    5.038987E+00    0.000000E+00    3.149367E+00    0.000000E+00
   1     1005    LS    0.000000E+00    0.000000E+00    5.475139E+00    0.000000E+00    3.421962E+00    0.000000E+00
   1     1006    LS    0.000000E+00    0.000000E+00    9.417634E+00    0.000000E+00    5.886021E+00    0.000000E+00
   1     1007    LS    0.000000E+00    0.000000E+00    1.629795E+01    0.000000E+00    1.018622E+01    0.000000E+00
   1     1100    LS    0.000000E+00    0.000000E+00    2.355297E+02    0.000000E+00    1.472061E+02    0.000000E+00
   1     1101    LS    0.000000E+00    0.000000E+00    6.142967E+01    0.000000E+00    3.839354E+01    0.000000E+00
   1     1102    LS    0.000000E+00    0.000000E+00    2.325008E+01    0.000000E+00    1.453130E+01    0.000000E+00
   1     1103    LS    0.000000E+00    0.000000E+00    8.182055E+00    0.000000E+00    5.113784E+00    0.000000E+00
   1     1104    LS    0.000000E+00    0.000000E+00    2.106187E+02    0.000000E+00    1.316367E+02    0.000000E+00
   1     1105    LS    0.000000E+00    0.000000E+00    7.771577E+01    0.000000E+00    4.857235E+01    0.000000E+00
   1     1106    LS    0.000000E+00    0.000000E+00    3.315908E+01    0.000000E+00    2.072442E+01    0.000000E+00
   1     1107    LS    0.000000E+00    0.000000E+00    1.016384E+01    0.000000E+00    6.352402E+00    0.000000E+00
   1     1108    LS    0.000000E+00    0.000000E+00    2.235292E+02    0.000000E+00    1.397057E+02    0.000000E+00
   1     1109    LS    0.000000E+00    0.000000E+00    8.758272E+01    0.000000E+00    5.473920E+01    0.000000E+00
   1     1110    LS    0.000000E+00    0.000000E+00    4.157019E+01    0.000000E+00    2.598137E+01    0.000000E+00
   1     1111    LS    0.000000E+00    0.000000E+00    1.071129E+01    0.000000E+00    6.694557E+00    0.000000E+00
   1     1112    LS    0.000000E+00    0.000000E+00    1.983261E+02    0.000000E+00    1.239538E+02    0.000000E+00
   1     1113    LS    0.000000E+00    0.000000E+00    8.676040E+01    0.000000E+00    5.422525E+01    0.000000E+00
   1     1114    LS    0.000000E+00    0.000000E+00    4.808368E+01    0.000000E+00    3.005230E+01    0.000000E+00
   1     1115    LS    0.000000E+00    0.000000E+00    2.146401E+01    0.000000E+00    1.341500E+01    0.000000E+00
   1     1116    LS    0.000000E+00    0.000000E+00    1.754358E+02    0.000000E+00    1.096474E+02    0.000000E+00
   1     1117    LS    0.000000E+00    0.000000E+00    7.952851E+01    0.000000E+00    4.970532E+01    0.000000E+00
   1     1118    LS    0.000000E+00    0.000000E+00    4.813270E+01    0.000000E+00    3.008294E+01    0.000000E+00
   1     1119    LS    0.000000E+00    0.000000E+00    2.483655E+01    0.000000E+00    1.552284E+01    0.000000E+00
   1     1120    LS    0.000000E+00    0.000000E+00    1.515861E+02    0.000000E+00    9.474129E+01    0.000000E+00
   1     1121    LS    0.000000E+00    0.000000E+00    6.920568E+01    0.000000E+00    4.325355E+01    0.000000E+00
   1     1122    LS    0.000000E+00    0.000000E+00    4.427624E+01    0.000000E+00    2.767265E+01    0.000000E+00
   1     1123    LS    0.000000E+00    0.000000E+00    2.502627E+01    0.000000E+00    1.564142E+01    0.000000E+00
   1     1124    LS    0.000000E+00    0.000000E+00    1.233664E+02    0.000000E+00    7.710403E+01    0.000000E+00
   1     1125    LS    0.000000E+00    0.000000E+00    5.584051E+01    0.000000E+00    3.490032E+01    0.000000E+00
   1     1126    LS    0.000000E+00    0.000000E+00    3.719299E+01    0.000000E+00    2.324562E+01    0.000000E+00
   1     1127    LS    0.000000E+00    0.000000E+00    2.286240E+01    0.000000E+00    1.428900E+01    0.000000E+00
   1     1128    LS    0.000000E+00    0.000000E+00    8.487065E+01    0.000000E+00    5.304415E+01    0.000000E+00
   1     1129    LS    0.000000E+00    0.000000E+00    3.709618E+01    0.000000E+00    2.318511E+01    0.000000E+00
   1     1130    LS    0.000000E+00    0.000000E+00    2.544671E+01    0.000000E+00    1.590420E+01    0.000000E+00
   1     1131    LS    0.000000E+00    0.000000E+00    1.735413E+01    0.000000E+00    1.084633E+01    0.000000E+00

      *** LABEL NOTATIONS:  LS = LIFTING SURFACE,   ZSB =  Z SLENDER BODY ELEMENT,  YSB =  Y SLENDER BODY ELEMENT,
                                                   ZYSB = ZY SLENDER BODY ELEMENT, EXTA = EXTERNAL AERO.

                                                         AEROELASTIC TRIM VARIABLES

                                  ID     LABEL                TYPE        TRIM STATUS      VALUE OF UX

                                         INTERCEPT         RIGID BODY          FIXED      0.000000E+00
                                 501     ANGLEA            RIGID BODY          FIXED      1.000000E+00  RADIANS
                                 502     PITCH             RIGID BODY          FIXED      0.000000E+00  NONDIMEN. RATE
                                 503     URDD3             RIGID BODY          FIXED      0.000000E+00  LOAD FACTOR
                                 504     URDD5             RIGID BODY          FIXED      0.000000E+00  RAD/S/S PER G
                                 505     ELEV          CONTROL SURFACE         FIXED      0.000000E+00  RADIANS

                         A E R O S T A T I C   D A T A   R E C O V E R Y   O U T P U T   T A B L E S
                    CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
                                  MACH = 9.000000E-01                    Q = 1.200000E+03
                    CHORD = 1.0000E+01          SPAN = 4.0000E+01           AREA = 2.0000E+02
```

Listing 7-26 Output for Unit Solutions of Example HA144GB (Continued)

```
                    AERODYNAMIC PRESSURES ON THE AERODYNAMIC ELEMENTS

                                   AERODYNAMIC PRES.       AERODYNAMIC
               GRID   LABEL          COEFFICIENTS            PRESSURES
                 1     LS            7.638809E+00          9.166571E+03
                 2     LS            1.767497E+00          2.120997E+03
                 3     LS            1.290208E+00          1.548250E+03
                 4     LS            1.606494E+00          1.927793E+03
                 5     LS            6.041941E+00          7.250330E+03
                 6     LS            1.298661E+00          1.558393E+03
                 7     LS            1.019577E+00          1.223493E+03
                 8     LS            1.433167E+00          1.719801E+03
                 9     LS            1.291074E+01          1.549289E+04
                10     LS            3.628104E+00          4.353725E+03
                11     LS            1.392012E+00          1.670415E+03
                12     LS            4.928885E-01          5.914662E+02
                13     LS            1.345261E+01          1.614314E+04
                14     LS            4.678053E+00          5.613664E+03
                15     LS            2.022728E+00          2.427273E+03
                16     LS            5.607064E-01          6.728477E+02
                17     LS            2.084907E+01          2.501888E+04
                18     LS            6.215151E+00          7.458181E+03
                19     LS            2.683740E+00          3.220488E+03
                20     LS            5.237644E-01          6.285173E+02
                21     LS            1.768373E+01          2.122047E+04
                22     LS            7.104996E+00          8.525995E+03
                23     LS            3.455574E+00          4.146689E+03
                24     LS            1.429338E+00          1.715205E+03
                25     LS            1.517674E+01          1.821209E+04
                26     LS            6.764282E+00          8.117139E+03
                27     LS            3.771949E+00          4.526339E+03
                28     LS            1.792641E+00          2.151170E+03
                29     LS            1.286854E+01          1.544225E+04
                30     LS            5.904086E+00          7.084903E+03
                31     LS            3.638149E+00          4.365778E+03
                32     LS            1.926709E+00          2.312050E+03
                33     LS            1.034012E+01          1.240815E+04
                34     LS            4.739939E+00          5.687927E+03
                35     LS            3.116377E+00          3.739652E+03
                36     LS            1.840011E+00          2.208013E+03
                37     LS            7.047599E+00          8.457119E+03
                38     LS            3.130688E+00          3.756825E+03
                39     LS            2.145971E+00          2.575166E+03
                40     LS            1.430287E+00          1.716344E+03

*** LABEL NOTATIONS:  LS = LIFTING SURFACE,   ZIB = Z INTERFERENCE BODY ELEMENT,  ZSB = Z SLENDER BODY ELEMENT,
                                              YIB = Y INTERFERENCE BODY ELEMENT,  YSB = Y SLENDER BODY ELEMENT.

          A E R O S T A T I C   D A T A   R E C O V E R Y   O U T P U T   T A B L E S
    CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
                     MACH = 9.000000E-01                Q = 1.200000E+03
    CHORD = 1.0000E+01           SPAN = 4.0000E+01           AREA = 2.0000E+02
```

Listing 7-26 Output for Unit Solutions of Example HA144GB (Continued)

AERODYNAMIC FORCES ON THE AERODYNAMIC ELEMENTS

GROUP	GRID ID	LABEL	T1	T2	T3	R1	R2	R3
1	1000	LS	0.000000E+00	0.000000E+00	5.729107E+04	0.000000E+00	3.580692E+04	0.000000E+00
1	1001	LS	0.000000E+00	0.000000E+00	1.325623E+04	0.000000E+00	8.285144E+03	0.000000E+00
1	1002	LS	0.000000E+00	0.000000E+00	9.676562E+03	0.000000E+00	6.047851E+03	0.000000E+00
1	1003	LS	0.000000E+00	0.000000E+00	1.204871E+04	0.000000E+00	7.530443E+03	0.000000E+00
1	1004	LS	0.000000E+00	0.000000E+00	4.531456E+04	0.000000E+00	2.832160E+04	0.000000E+00
1	1005	LS	0.000000E+00	0.000000E+00	9.739955E+03	0.000000E+00	6.087472E+03	0.000000E+00
1	1006	LS	0.000000E+00	0.000000E+00	7.646830E+03	0.000000E+00	4.779269E+03	0.000000E+00
1	1007	LS	0.000000E+00	0.000000E+00	1.074876E+04	0.000000E+00	6.717972E+03	0.000000E+00
1	1100	LS	0.000000E+00	0.000000E+00	9.683054E+04	0.000000E+00	6.051909E+04	0.000000E+00
1	1101	LS	0.000000E+00	0.000000E+00	2.721078E+04	0.000000E+00	1.700674E+04	0.000000E+00
1	1102	LS	0.000000E+00	0.000000E+00	1.044009E+04	0.000000E+00	6.525059E+03	0.000000E+00
1	1103	LS	0.000000E+00	0.000000E+00	3.696664E+03	0.000000E+00	2.310415E+03	0.000000E+00
1	1104	LS	0.000000E+00	0.000000E+00	1.008946E+05	0.000000E+00	6.305913E+04	0.000000E+00
1	1105	LS	0.000000E+00	0.000000E+00	3.508540E+04	0.000000E+00	2.192837E+04	0.000000E+00
1	1106	LS	0.000000E+00	0.000000E+00	1.517046E+04	0.000000E+00	9.481537E+03	0.000000E+00
1	1107	LS	0.000000E+00	0.000000E+00	4.205298E+03	0.000000E+00	2.628311E+03	0.000000E+00
1	1108	LS	0.000000E+00	0.000000E+00	1.563680E+05	0.000000E+00	9.773001E+04	0.000000E+00
1	1109	LS	0.000000E+00	0.000000E+00	4.661363E+04	0.000000E+00	2.913352E+04	0.000000E+00
1	1110	LS	0.000000E+00	0.000000E+00	2.012805E+04	0.000000E+00	1.258003E+04	0.000000E+00
1	1111	LS	0.000000E+00	0.000000E+00	3.928233E+03	0.000000E+00	2.455146E+03	0.000000E+00
1	1112	LS	0.000000E+00	0.000000E+00	1.326279E+05	0.000000E+00	8.289246E+04	0.000000E+00
1	1113	LS	0.000000E+00	0.000000E+00	5.328747E+04	0.000000E+00	3.330467E+04	0.000000E+00
1	1114	LS	0.000000E+00	0.000000E+00	2.591680E+04	0.000000E+00	1.619800E+04	0.000000E+00
1	1115	LS	0.000000E+00	0.000000E+00	1.072003E+04	0.000000E+00	6.700021E+03	0.000000E+00
1	1116	LS	0.000000E+00	0.000000E+00	1.138256E+05	0.000000E+00	7.114098E+04	0.000000E+00
1	1117	LS	0.000000E+00	0.000000E+00	5.073212E+04	0.000000E+00	3.170757E+04	0.000000E+00
1	1118	LS	0.000000E+00	0.000000E+00	2.828962E+04	0.000000E+00	1.768101E+04	0.000000E+00
1	1119	LS	0.000000E+00	0.000000E+00	1.344481E+04	0.000000E+00	8.403007E+03	0.000000E+00
1	1120	LS	0.000000E+00	0.000000E+00	9.651404E+04	0.000000E+00	6.032128E+04	0.000000E+00
1	1121	LS	0.000000E+00	0.000000E+00	4.428064E+04	0.000000E+00	2.767540E+04	0.000000E+00
1	1122	LS	0.000000E+00	0.000000E+00	2.728612E+04	0.000000E+00	1.705382E+04	0.000000E+00
1	1123	LS	0.000000E+00	0.000000E+00	1.445031E+04	0.000000E+00	9.031446E+03	0.000000E+00
1	1124	LS	0.000000E+00	0.000000E+00	7.755093E+04	0.000000E+00	4.846933E+04	0.000000E+00
1	1125	LS	0.000000E+00	0.000000E+00	3.554954E+04	0.000000E+00	2.221847E+04	0.000000E+00
1	1126	LS	0.000000E+00	0.000000E+00	2.337282E+04	0.000000E+00	1.460801E+04	0.000000E+00
1	1127	LS	0.000000E+00	0.000000E+00	1.380008E+04	0.000000E+00	8.625050E+03	0.000000E+00
1	1128	LS	0.000000E+00	0.000000E+00	5.285699E+04	0.000000E+00	3.303562E+04	0.000000E+00
1	1129	LS	0.000000E+00	0.000000E+00	2.348016E+04	0.000000E+00	1.467510E+04	0.000000E+00
1	1130	LS	0.000000E+00	0.000000E+00	1.609479E+04	0.000000E+00	1.005924E+04	0.000000E+00
1	1131	LS	0.000000E+00	0.000000E+00	1.072715E+04	0.000000E+00	6.704470E+03	0.000000E+00

*** LABEL NOTATIONS: LS = LIFTING SURFACE, ZSB = Z SLENDER BODY ELEMENT, YSB = Y SLENDER BODY ELEMENT,
ZYSB = ZY SLENDER BODY ELEMENT, EXTA = EXTERNAL AERO.

0 HALF-SPAN MODEL, STATIC SYMMETRIC LOADING SUBCASE 1

D I S P L A C E M E N T V E C T O R

POINT ID.	TYPE	T1	T2	T3	R1	R2	R3
90	G	0.0	0.0	0.0	0.0	0.0	0.0
97	G	0.0	0.0	2.337641E-05	0.0	1.753231E-06	0.0
98	G	0.0	0.0	5.844103E-06	0.0	1.753231E-06	0.0
99	G	0.0	0.0	6.539141E-04	0.0	-2.208217E-04	0.0
100	G	0.0	0.0	2.312514E-03	0.0	4.265354E-05	0.0
110	G	0.0	0.0	4.003543E-03	3.714095E-04	3.860447E-04	0.0
111	G	0.0	0.0	4.968654E-03	3.714095E-04	3.860447E-04	0.0
112	G	0.0	0.0	3.038431E-03	3.714095E-04	3.860447E-04	0.0
120	G	0.0	0.0	1.244762E-02	6.134596E-04	6.468974E-04	0.0
121	G	0.0	0.0	1.406487E-02	6.134596E-04	6.468974E-04	0.0
122	G	0.0	0.0	1.083038E-02	6.134596E-04	6.468974E-04	0.0

0 HALF-SPAN MODEL, STATIC SYMMETRIC LOADING SUBCASE 2

D I S P L A C E M E N T V E C T O R

POINT ID.	TYPE	T1	T2	T3	R1	R2	R3
90	G	0.0	0.0	0.0	0.0	0.0	0.0
97	G	0.0	0.0	8.257083E-02	0.0	6.192812E-03	0.0
98	G	0.0	0.0	2.064271E-02	0.0	6.192812E-03	0.0
99	G	0.0	0.0	3.520744E-01	0.0	-1.170423E-01	0.0
100	G	0.0	0.0	1.070061E+00	0.0	6.436864E-02	0.0
110	G	0.0	0.0	2.231179E+00	2.300923E-01	2.817224E-01	0.0
111	G	0.0	0.0	2.935485E+00	2.300923E-01	2.817224E-01	0.0
112	G	0.0	0.0	1.526873E+00	2.300923E-01	2.817224E-01	0.0
120	G	0.0	0.0	7.741360E+00	3.824707E-01	4.487693E-01	0.0
121	G	0.0	0.0	8.863284E+00	3.824707E-01	4.487693E-01	0.0
122	G	0.0	0.0	6.619437E+00	3.824707E-01	4.487693E-01	0.0

Listing 7-26 Output for Unit Solutions of Example HA144GB (Continued)

```
0     HALF-SPAN MODEL, STATIC SYMMETRIC LOADING                                                   SUBCASE 1

                              F O R C E S   I N   B A R   E L E M E N T S       ( C B A R )
0    ELEMENT          BEND-MOMENT END-A            BEND-MOMENT END-B                - SHEAR -               AXIAL
       ID.          PLANE 1        PLANE 2        PLANE 1        PLANE 2        PLANE 1        PLANE 2        FORCE          TORQUE
         100     1.715266E+04  0.0           4.929496E+03  0.0           2.444634E+03  0.0           0.0            0.0
         101     0.0           0.0           0.0           0.0           0.0           0.0           0.0            0.0
         102     5.684342E-14  0.0           1.753230E+02  0.0          -3.506459E+01  0.0           0.0            0.0
         103     4.929496E+03  0.0          -1.810325E+04  0.0           2.303275E+03  0.0           0.0            0.0
         110     2.783045E+04  0.0           1.489451E+04  0.0           2.240570E+03  0.0           0.0            4.835922E+03
         120     1.341350E+04  0.0           1.311001E+03  0.0           1.048107E+03  0.0           0.0            2.270721E+03
0     HALF-SPAN MODEL, STATIC SYMMETRIC LOADING                                                   SUBCASE 2

                              F O R C E S   I N   B A R   E L E M E N T S       ( C B A R )
0    ELEMENT          BEND-MOMENT END-A            BEND-MOMENT END-B                - SHEAR -               AXIAL
       ID.          PLANE 1        PLANE 2        PLANE 1        PLANE 2        PLANE 1        PLANE 2        FORCE          TORQUE
         100     9.420227E+06  0.0           2.283996E+06  0.0           1.427246E+06  0.0           0.0            0.0
         101     0.0           0.0          -5.820766E-10  0.0           5.820766E-11  0.0           0.0            0.0
         102     2.328306E-10  0.0           6.192808E+05  0.0          -1.238562E+05  0.0           0.0            0.0
         103     2.283996E+06  0.0          -1.135454E+07  0.0           1.363853E+06  0.0           0.0            0.0
         110     1.721999E+07  0.0           9.448610E+06  0.0           1.346043E+06  0.0           0.0            3.169125E+06
         120     8.474887E+06  0.0           8.559712E+05  0.0           6.598175E+05  0.0           0.0            1.482586E+06
0     HALF-SPAN MODEL, STATIC SYMMETRIC LOADING                                                   SUBCASE 1

                              S T R E S S E S   I N   B A R   E L E M E N T S       ( C B A R )
  ELEMENT        SA1            SA2            SA3            SA4           AXIAL          SA-MAX         SA-MIN     M.S.-T
    ID.          SB1            SB2            SB3            SB4           STRESS         SB-MAX         SB-MIN     M.S.-C
0     100   -9.879940E+04  -9.879940E+04   9.879940E+04   9.879940E+04   0.0            9.879940E+04  -9.879940E+04
            -2.839391E+04  -2.839391E+04   2.839391E+04   2.839391E+04                  2.839391E+04  -2.839391E+04
0     101    0.0            0.0            0.0            0.0            0.0            0.0            0.0
             0.0            0.0            0.0            0.0                           0.0            0.0
0     102   -3.274183E-13  -3.274183E-13   3.274183E-13   3.274183E-13   0.0            3.274183E-13  -3.274183E-13
            -1.009861E+03  -1.009861E+03   1.009861E+03   1.009861E+03                  1.009861E+03  -1.009861E+03
0     103   -2.839391E+04  -2.839391E+04   2.839391E+04   2.839391E+04   0.0            2.839391E+04  -2.839391E+04
             1.042748E+05   1.042748E+05  -1.042748E+05  -1.042748E+05                  1.042748E+05  -1.042748E+05
0     110   -8.015174E+04  -8.015174E+04   8.015174E+04   8.015174E+04   0.0            8.015174E+04  -8.015174E+04
            -4.289623E+04  -4.289623E+04   4.289623E+04   4.289623E+04                  4.289623E+04  -4.289623E+04
0     120   -3.863089E+04  -3.863089E+04   3.863089E+04   3.863089E+04   0.0            3.863089E+04  -3.863089E+04
            -3.775685E+03  -3.775685E+03   3.775685E+03   3.775685E+03                  3.775685E+03  -3.775685E+03
0     HALF-SPAN MODEL, STATIC SYMMETRIC LOADING                                                   SUBCASE 2

                              S T R E S S E S   I N   B A R   E L E M E N T S       ( C B A R )
  ELEMENT        SA1            SA2            SA3            SA4           AXIAL          SA-MAX         SA-MIN     M.S.-T
    ID.          SB1            SB2            SB3            SB4           STRESS         SB-MAX         SB-MIN     M.S.-C
0     100   -5.426054E+07  -5.426054E+07   5.426054E+07   5.426054E+07   0.0            5.426054E+07  -5.426054E+07
            -1.315582E+07  -1.315582E+07   1.315582E+07   1.315582E+07                  1.315582E+07  -1.315582E+07
0     101    0.0            0.0            0.0            0.0            0.0            0.0            0.0
             3.352763E-09   3.352763E-09  -3.352763E-09  -3.352763E-09                  3.352763E-09  -3.352763E-09
0     102   -1.341105E-09  -1.341105E-09   1.341105E-09   1.341105E-09   0.0            1.341105E-09  -1.341105E-09
            -3.567060E+06  -3.567060E+06   3.567060E+06   3.567060E+06                  3.567060E+06  -3.567060E+06
0     103   -1.315582E+07  -1.315582E+07   1.315582E+07   1.315582E+07   0.0            1.315582E+07  -1.315582E+07
             6.540217E+07   6.540217E+07  -6.540217E+07  -6.540217E+07                  6.540217E+07  -6.540217E+07
0     110   -4.959361E+07  -4.959361E+07   4.959361E+07   4.959361E+07   0.0            4.959361E+07  -4.959361E+07
            -2.721201E+07  -2.721201E+07   2.721201E+07   2.721201E+07                  2.721201E+07  -2.721201E+07
0     120   -2.440769E+07  -2.440769E+07   2.440769E+07   2.440769E+07   0.0            2.440769E+07  -2.440769E+07
            -2.465198E+06  -2.465198E+06   2.465198E+06   2.465198E+06                  2.465198E+06  -2.465198E+06
```

Separate Rigid and Flexible Meshes

The External Aerodynamics writeup of Chapter 3 documents how you can provide your own aerodynamics in an aeroelastic analysis. These aerodynamics could come from testing, an advanced panel method or CFD aerodynamics. Typically, these aerodynamics have no means of readily incorporating the aeroelastic effects of applying these loads to deforming structure, so that this aeroelastic feedback mechanism is neglected. The Rigid/Flexible Aerodynamics topic of Chapter 3 details how MSC Nastran's internal aerodynamics can be coupled with the external aerodynamics to provide an aeroelastic correction. In terms of Equation (2-110), the $[Q_{aa}]$ terms come from internal aerodynamic while the $[Q_{ax}]$ terms come from external aerodynamics. This example shows a simple application of this concept using a variation of the 15-Degree Sweptback Wing in a Wind Tunnel example from earlier in this chapter as a basis using two input decks that are executed in series.

The first deck is HA144IR shown in Listing 7-27. The structure in input using the same PLATEST.DAT file of Listing 7-10 and much of the remaining input is similar to the earlier example, but there are important differences. In case control, it is important to note the AECONFIG=RAERO. The configuration used here will be used in the second step to identify the datablocks that will be used for the rigid loads. The wing is no longer cantilevered, but now SUPORTs pitch and plunge at grid 17. A stabilizer surface is added that has a configuration represented by four AEGRID locations. No underlying structure is provided for the stabilizer. No CAEROx entries are used for the external aerodynamics. Instead, AEFORCE, UXVEC and DMIK entries are used to provide rigid aerodynamic loads for the Intercept, angle of attack and stabilizer. In this simple example, the external aerodynamics were obtained from a separate run which used the Unit Solution technique of the previous example to produce loads for the three states (one would never do this in practice). It is seen that in addition to the AEGRIDs representing the stabilizer, 40 AEGRIDs are provided that match the location of the structural mesh shown in Figure 7-11 (a). Note that there is no requirement that this aerodynamic mesh and the structural mesh align; typically the aero mesh locations would be dictated by the aerodynamic program providing the aerodynamics. There is no necessity for AEQUAD4 entries in this case.

Listing 7-27 Input Data file Rigid Aerodynamics of Example HA144IR

```
ID MSC, HA144IR
$$$$$$$$ AEROELASTIC USER'S GUIDE EXAMPLE HA144IR              $$$$$$$$
$                                                                     $
$       MODEL DESCRIPTION       MODEL A OF NASA TN D-1824             $
$                               HALF SPAN 15 DEGREE SWEPT WING        $
$                               28 QUAD4 PANEL MODEL                  $
$                                                                     $
$       SOLUTION                USER PROVIDED RIGID AERODYNAMICS      $
$                               NO AEROELASTIC CORRECTION             $
$                                                                     $
$                                                                     $
$$$$$$$$                                                       $$$$$$$$
DIAG 8 $
SOL 144  $ STATIC AERO
CEND


TITLE = EXAMPLE HA144C: HALF SPAN 15-DEG SWEPT UNTAPERED WING  HA144C
SUBT  = FREE SYMMEWTRIC STRUCTURE. USER INPUT AERODYNAMICS
LABEL = 0.041 IN PLATE W/BEVELLED LEADING AND TRAILING EDGES
  AECONFIG = RAERO
  ECHO   = BOTH
  SPC    = 1
  DISP   = ALL
  STRESS = ALL
  FORCE  = ALL
  AEROF  = ALL
  APRES  = ALL
  TRIM = 1
  TRIMF(RIGID,INERTIA,AIR,APPLIED) = ALL
$
```

Listing 7-27 Input Data file Rigid Aerodynamics of Example HA144IR (Continued)

```
BEGIN BULK
$*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
$                                                                           $
$        THE ANNOTATIONS IN THIS INPUT DECK ARE INTENDED TO                 $
$        EXPLAIN THE DATA ON THE CARD IMAGES FOR THIS                       $
$        EXAMPLE WITHOUT REFERENCE TO THE VARIOUS MANUALS WHERE             $
$        MORE GENERAL DESCRIPTIONS WILL BE FOUND.                           $
$                                                                           $
INCLUDE 'PLATEST.DAT'
$                                                                           $
$        THE RBAR ENTRY DEFINES A RIGID BAR WITH SIX DEGREES OF             $
$        FREEDOM AT EACH END.  LISTED ARE THE GRID POINT NUMBERS,           $
$        THE INDEPENDENT AND THE DEPENDENT DOFS AT THE TWO ENDS.            $
$                                                                           $
$       EID     GA      GB      CNA     CNB     CMA     CMB                 $
RBAR    101     17      9       123456
RBAR    102     17      25      123456
$                                                                           $
$                **  MASS AND INERTIA PROPERTIES * *                        $
$                                                                           $
$        THE MAT1 ENTRY DEFINES THE MATERIAL PROPERTIES FOR LINEAR,         $
$        TEMPERATURE-INDEPENDENT, ISOTROPIC MATERIALS.  IT LISTS            $
$        YOUNGS MODULUS, THE SHEAR MODULUS, POISSONS RATIO MASS             $
$        DENSITY, THERMAL EXPANSION COEFFICIENT AND STRUCTURAL              $
$        ELEMENT DAMPING.                                                   $
$                                                                           $
$       MID     E       G       NU      RHO     A       TREF    GE
MAT1    1       10.3+6  3.9+6           0.1
$                                                                           $
$                                                                           $
PARAM   AUNITS  .0025901
PARAM   GRDPNT17
$                                                                           $
$                   * * STRUCTURAL CONSTRAINTS * *                          $
$                                                                           $
$        THE SUPORT ENTRY IDENTIFIES A DOF IN WHICH THE USER DESIRES        $
$        DETERMINATE REACTIONS TO BE APPLIED TO PREVENT RIGID BODY          $
$        MOTION. IT INVOKES THE SOLUTION OF THE BALANCE EQUATIONS TO        $
$        DETERMINE THE REACTIONS.  IN THE STATIC AEROELASTIC SOLUTION       $
$        THE DOF COMPONENTS MUST BE CONSISTENT WITH THE UNDEFINED           $
$        VARIABLES ON THE TRIM ENTRIES.  IT IS ALSO IMPORTANT THAT          $
$        NO OTHER POINT ON THE STRUCTURE BE CONSTRAINED IN THESE            $
$        DOFS; OTHERWISE, UNDETERMINED CONSTRAINT FORCES WILL BE            $
$        IMPOSED AND THE REACTIONS AT THE SUPORT POINT WILL NOT             $
$        BE THE TOTAL OF THE REACTION FORCES.                               $
$                                                                           $
$       ID      C                                                           $
SUPORT  17      35
$                                                                           $
$        THE SPC1 ENTRY DEFINES SETS OF SINGLE-POINT CONSTRAINTS.           $
$        IT LISTS ITS ID, THE DOF COMPONENTS TO BE CONSTRAINED              $
$        AND THE GRID POINT NO.                                             $
$                                                                           $
$       SID     C       G1      G2      ETC.
SPC1    1       1246    17
SPC1    1       6       1       THRU    8
SPC1    1       6       10      THRU    16
SPC1    1       6       18      THRU    24
SPC1    1       6       26      THRU    40
$
```

Listing 7-27 Input Data file Rigid Aerodynamics of Example HA144IR (Continued)

```
$                    * * * AERODYNAMIC DATA * * *                     $
$                                                                     $
$                         (LB-IN-SEC SYSTEM)                          $
$                                                                     $
$                      * * ELEMENT GEOMETRY * *                       $
$                                                                     $
$        THE AEROS ENTRY IS UNIQUE TO THE STATIC AEROELASTICITY       $
$        SOLUTION, SOL21.  ACSID IDENTIFIES THE AERO COORDINATE       $
$        SYSTEM.  RCSID IDENTIFIES THE REFERENCE COORDINATE SYS-      $
$        TEM FOR RIGID BODY MOTION.  REFC IS THE REFERENCE CHORD.     $
$        REFB IS THE REFERENCE SPAN (NOT THE SEMI-SPAN).  REFS IS     $
$        THE REFERENCE WING AREA (FOR ONE SIDE ONLY, IN THIS CASE).   $
$        SYMXZ AND SYMXY ARE SYMMETRY KEYS THAT SPECIFY THE           $
$        PRESENCE OF REFLECTION PLANES ONLY, NOT THE EXISTENCE OF     $
$        OTHER LIFTING SURFACES.                                      $
$                                                                     $
$       ACSID   RCSID   REFC    REFB    REFS    SYMXZ   SYMXY
AEROS   0       11      2.07055 11.0502 11.4400 1
$                                                                     $
$        THIS CORD2R ENTRY DEFINES THE AERO COORDINATE SYSTEM         $
$        FLAGGED BY THE AEROS ENTRY.  THE ORIGIN IS AT THE WING       $
$        SUPPORT POINT (GRID 17).  LISTED ARE THE ORIGIN, A POINT     $
$        ON THE Z-AXIS AND A POINT ON THE X-AXIS, ALL IN THE RID      $
$        COORDINATE SYSTEM.                                           $
$                                                                     $
$       CID     RID     A1      A2      A3      B1      B2      B3
CORD2R  11              1.035275 0.0    0.0     1.035275 0.0    1.0     +CORD1
$       C1      C2      C3
+CORD1  2.0     0.0     0.0
$                                                                     $
$                                                                     $
$       EID     CAERO   BOX1    BOX2    SETG    DZ
SPLINE4 100     101     101             100     .0      IPS
AELIST  101     2       4       6       8       9       11      13      +S1
+S1     15      18      20      22      24      25      27      29      +S2
+S2     31      34      36      38      4017
SPLINRB 101     101     10217123456
AELIST102101102103104
AEGRID  1                0.0     0.0     0.0
AEGRID  2                .211491 .7893   0.0
AEGRID  3                .422983 1.5786  0.0
AEGRID  4                .634474 2.3679  0.0
AEGRID  5                .845966 3.1572  0.0
AEGRID  6                1.05746 3.9465  0.0
AEGRID  7                1.26895 4.7358  0.0
AEGRID  8                1.48044 5.5251  0.0
AEGRID  9                .258819 0.0     0.0
AEGRID  10               .47031  .7893   0.0
AEGRID  11               .681802 1.5786  0.0
AEGRID  12               .893293 2.3679  0.0
AEGRID  13               1.10478 3.1572  0.0
AEGRID  14               1.31628 3.9465  0.0
AEGRID  15               1.52777 4.7358  0.0
AEGRID  16               1.73926 5.5251  0.0
AEGRID  17               1.03528 0.0     0.0
AEGRID  18               1.24677 .7893   0.0
AEGRID  19               1.45826 1.5786  0.0
AEGRID  20               1.66975 2.3679  0.0
AEGRID  21               1.88124 3.1572  0.0
AEGRID  22               2.09273 3.9465  0.0
AEGRID  23               2.30422 4.7358  0.0
AEGRID  24               2.51572 5.5251  0.0
AEGRID  25               1.81173 0.0     0.0
AEGRID  26               2.02322 .7893   0.0
AEGRID  27               2.23471 1.5786  0.0
AEGRID  28               2.44621 2.3679  0.0
AEGRID  29               2.6577  3.1572  0.0
AEGRID  30               2.86919 3.9465  0.0
AEGRID  31               3.08068 4.7358  0.0
AEGRID  32               3.29217 5.5251  0.0
AEGRID  33               2.07055 0.0     0.0
AEGRID  34               2.28204 .7893   0.0
AEGRID  35               2.49353 1.5786  0.0
AEGRID  36               2.70502 2.3679  0.0
AEGRID  37               2.91652 3.1572  0.0
AEGRID  38               3.12801 3.9465  0.0
AEGRID  39               3.3395  4.7358  0.0
AEGRID  40               3.55099 5.5251  0.0
```

Listing 7-27 Input Data file Rigid Aerodynamics of Example HA144IR (Continued)

```
$    TAIL AEGRIDS
AEGRID  101             8.0     0.0     0.0
AEGRID  102             8.0     2.5     0.0
AEGRID  103             9.0     0.0     0.0
AEGRID  104             9.0     2.5     0.0
AEQUAD4101101184033
AEQUAD4102101101     102     104     103
$    AERO FOR UNIT ANGLE OF ATTACK
AEFORCE 0.45SYMMASYMM101AEROANGLEA
DMIKANGLEA  091       01
DMIKANGLEA 11234.74
434.16633.72
8 31.119 32.21
1136.50 1336.67
1535.491730.0
18 34.9720      34.31
22 3 3.66     2430.92
        253       0.56273       1.18
        293       1.06313.856
        343       0.037363-.137
        383       -.14            403-.21
       101     3       4.5102     3       2.7
       103     3       1.35           10430.45
UXVEC101
INTERCPT 0.0    ANGLEA  1.0
$    AERO FOR UNIT STABILIZER
AEFORCE 0.45SYMMASYMM102AEROSTAB
DMIKSTAB 091       01
DMIKSTAB 1118 30.5
10135.75     10233.45
10331.72 10430.5
UXVEC102
INTERCPT 0.0STAB    1.0
$    AERO FOR INTERCEPT
AEFORCE 0.45SYMMASYMM103AEROINTER
DMIKINTER091       01
DMIKINTER11230.82
430.72630.64
8 30.199 30.38
1131.12 1331.15
1530.951730.0
18 30.85 20      30.75
22 3 0.63     2430.17
        253       0.095273       0.20
        293       0.1833130.183
        343       0.006363-0.02
        383       -0.02           403-0.04
       101     3       -0.25   102     3       -0.15
       103     3       -0.075          1043-0.02
UXVEC103
INTERCPT 1.0
$                                                                       $
$        THE SET1 ENTRY DEFINES THE STRUCTURAL GRID POINTS TO           $
$        BE USED BY THE SURFACE SPLINE FOR INTERPOLATION.               $
$                                                                       $
$       SID     G1      G2      G3      G4      G5      G6
SET1    100     2       4       6       8       9       11      13      +S1
+S1     15      18      20      22      24      25      27      29      +S2
+S2     31      34      36      38      40
$                                                                       $
$                   * * USER SUPPLIED AERO DATA * *                     $
$                                                                       $
$        THE DMI ENTRY ACCOMMODATES DIRECT INPUT OF USER SUPPLIED       $
$        MATRICES OF DATA.  LISTED ARE THE NAME OF THE MATRIX, THE      $
$        FORM OF MATRIX, THE TYPE OF DATA BEING INPUT, AND THE TYPE     $
$        EXPECTED AS OUTPUT.  M IS THE NUMBER OF ROWS AND N IS THE      $
$        NUMBER OF COLUMNS.  THE DATA ARE EXPECTED BY COLUMNS.  THE     $
$        CONTINUATION ENTRY LISTS THE COLUMN NO., THE ROW NO. OF THE    $
$        FIRST NON-ZERO ELEMENT AND THE FOLLOWING ELEMENTS IN THAT      $
$        COLUMN.                                                        $
$                                                                       $
$     * INITIAL DOWNWASHES (E.G., DUE TO INCIDENCE,TWIST OR CAMBER) *   $
$                                                                       $
$               * * * STATIC AEROELASTIC SOLUTION * * *                 $
$                                                                       $
$                       * * AERODYNAMIC DOFS * *                        $
$                                                                       $
$        THE AESTAT ENTRY LISTS TRIM VARIABLES USED TO SPECIFY          $
$        RIGID BODY MOTIONS.  THESE AND THE CONTROL SURFACE             $
$        ROTATIONS MAKE UP THE VARIABLES IN THE EQUATIONS OF            $
$        MOTION.                                                        $
$                                                                       $
AEPARM  501     ANGLEA  RADIANS
AESURF  502     STAB 101101NOLDW
```

Listing 7-27 Input Data file Rigid Aerodynamics of Example HA144IR (Continued)

```
AESTAT  503     URDD3
AESTAT  505     URDD5
CORD2R  1018.50.00.08.50.01.0
9.00.00.0
$                                                                           $
$                      * * TRIM CONDITIONS * *                              $
$                                                                           $
$        THE TRIM ENTRY SPECIFIES CONSTRAINTS FOR THE TRIM VARIABLES        $
$        LISTED ON THE AESTAT AND AESURF ENTRIES.  LISTED ARE ITS ID,       $
$        THE MACH NUMBER, DYNAMIC PRESSURE AND PAIRS OF TRIM VARI-          $
$        ABLES AND THEIR CONSTRAINED VALUES.  THOSE THAT ARE NOT            $
$        HELD FIXED MUST BE CONSTRAINED BY REACTION FORCES STIPU-           $
$        LATED ON THE SUPORT ENTRY.                                         $
$                                                                           $
TRIM    1       0.45    2.0     URDD3   1.0 URDD50.0
ENDDATA
```

The states for the external aerodynamics are input using AESTAT (for URDD3 and URDD5), AEPARM for ANGLEA and AESURF for the STABilizer. Field 10 of the AESURF entry contains NOLDW, which indicates that the loads for this surface need to be provided by the user. Each load requires AEFORCE, UXVEC and DMIK data. Note that AESTAT ANGLEA is a reserved quantity for internal aerodynamics so it is required that an AEPARM be used for ANGLEA and the same name be used to sync up with the flexible correction of the subsequent run. The AEFORCE entry provides Mach number and symmetry information, points to the associated UXVEC and identifies the associated DMIK data. The AERO field indicates this is for aerodynamic input since the AEFORCE entry can also be used for STRUCTural input. The UXVEC data identifies the state that is being defined for this load. There is an inferred value of INTERCPT=1.0 for each state so that in this example it is necessary to explicitly set INTECPT=0.0 for the ANGLEA and STAB states. The actual forces associated with the state are input using the DMIK entry. The name matches that of the AEFORCE entry and the loads are input as a triplet of AEGRID ID, component and magnitude.

There are two splines for this model. The first is a SPLINE4 that provides interpolation between the wing structure and the aero mesh that represents the wing. The AEGRIDs called out on the AELIST entry for the aerodynamic grids are identical to the GRIDS called out on the SET1 entry, but this is simply an artifact of the simplified example. The second spline is a SPLINRB and provides a way of transferring loads from the aerodynamic model that does not have an underlying structure to some point on the structure using a rigid body transformation. In this case, aerodynamic loads applied to AEGRID's 101-104 are transferred to structural grid 17.

The TRIM task is to perform a 1g maneuver at M=0.45 and q=2.0 psi. The job is run while specifying SCR=NO so that the database will be saved for reuse in the second run.

Selected results are shown in Listing 7-28. The listing starts with the stability derivatives and the absence of aeroelastic corrections is evident by the fact that the rigid and elastic derivatives are identical. It is also noted that the splined and unsplined derivatives are the same, indicating that the splines, including the SPLINRB, have done their job well. The trim results depict a flight angle of attack of -10.0 degrees and a stabilizer setting of 10.31 degrees. From the displacement output, it is seen that the tip is deflecting a maximum of -0.0081 inches for this 1g maneuver.

Listing 7-28 Output for Rigid Aerodynamics of Example HA144IR

```
 N O N - D I M E N S I O N A L   S T A B I L I T Y   A N D   C O N T R O L   D E R I V A T I V E   C O E F F I C I E N T S

                        CONFIGURATION = RAERO        XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
                                        MACH = 4.5000E-01                   Q = 2.0000E+00
                        CHORD = 2.0705E+00           SPAN = 1.1050E+01           AREA = 1.1440E+01

                 TRANSFORMATION FROM BASIC TO REFERENCE COORDINATES:

               { X }         [  1.0000   0.0000   0.0000  ]  { X }        {-1.0353E+00 }
               { Y }     =   [  0.0000   1.0000   0.0000  ]  { Y }      + { 0.0000E+00 }
               { Z }REF      [  0.0000   0.0000   1.0000  ]  { Z }BAS     { 0.0000E+00 }

     CONTROLLER STATE: INTERCEPT ONLY, ALL CONTROLLERS ARE ZERO

     TRIM VARIABLE    COEFFICIENT           RIGID                         ELASTIC                           INERTIAL
                                  UNSPLINED        SPLINED       RESTRAINED      UNRESTRAINED      RESTRAINED      UNRESTRAINED

     REF. COEFF.       CX        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                       CY        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                       CZ        7.396853E-01    7.396853E-01    7.396853E-01    7.396853E-01    0.000000E+00    7.396853E-01
                       CMX       0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                       CMY       9.123180E-02    9.123180E-02    9.123180E-02    9.123180E-02    0.000000E+00    9.123180E-02
                       CMZ       0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00

     ANGLEA            CX        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                       CY        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                       CZ        5.302972E+00    5.302972E+00    5.302972E+00    5.302972E+00    0.000000E+00    5.302972E+00
                       CMX       0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                       CMY      -3.038611E+00   -3.038611E+00   -3.038611E+00   -3.038611E+00    0.000000E+00   -3.038611E+00
                       CMZ       0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00

     STAB              CX        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                       CY        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                       CZ        1.041958E+00    1.041958E+00    1.041958E+00    1.041958E+00    0.000000E+00    1.041958E+00
                       CMX       0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                       CMY      -3.456013E+00   -3.456013E+00   -3.456013E+00   -3.456013E+00    0.000000E+00   -3.456013E+00
                       CMZ       0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00

     URDD3             CX        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                       CY        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                       CZ        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    1.793749E-03    0.000000E+00
                       CMX       0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                       CMY       0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00   -6.412642E-04    0.000000E+00
                       CMZ       0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00

     URDD5             CX        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                       CY        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                       CZ        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00   -1.327770E-03    0.000000E+00
                       CMX       0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
                       CMY       0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    8.747027E-04    0.000000E+00
                       CMZ       0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
1     EXAMPLE HA144C: HALF SPAN 15-DEG SWEPT UNTAPERED WING  HA144C            JUNE  25, 2019  MSC Nastran  6/24/19    PAGE    24
       FREE SYMMEWTRIC STRUCTURE. USER INPUT AERODYNAMICS
0      0.041 IN PLATE W/BEVELLED LEADING AND TRAILING EDGES
          N O N - D I M E N S I O N A L   H I N G E   M O M E N T   D E R I V A T I V E   C O E F F I C I E N T S


                        CONFIGURATION = RAERO        XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
                                        MACH = 4.5000E-01                   Q = 2.0000E+00

           CONTROL SURFACE = STAB         REFERENCE CHORD LENGTH =  1.000000E+00     REFERENCE AREA =  1.000000E+00

               TRIM VARIABLE              RIGID                          ELASTIC                            INERTIAL
                                                             RESTRAINED      UNRESTRAINED          RESTRAINED      UNRESTRAINED
               AT REFERENCE         6.548002E+01             6.548002E+01    6.548002E+01          0.000000E+00    0.000000E+00
               ANGLEA               3.781791E+02             3.781791E+02    3.781791E+02          0.000000E+00    0.000000E+00
               STAB                 3.626615E+00             3.626615E+00    3.626615E+00          0.000000E+00    0.000000E+00
               URDD3                0.000000E+00             0.000000E+00    0.000000E+00          0.000000E+00    0.000000E+00
               URDD5                0.000000E+00             0.000000E+00    0.000000E+00          0.000000E+00    0.000000E+00
```

Listing 7-28 Output for Rigid Aerodynamics of Example HA144IR

```
A E R O S T A T I C   D A T A   R E C O V E R Y   O U T P U T   T A B L E S
                        CONFIGURATION = RAERO         XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
                                          MACH = 4.500000E-01                   Q = 2.000000E+00
                        CHORD = 2.0705E+00            SPAN = 1.1050E+01            AREA = 1.1440E+01

         TRIM ALGORITHM USED: LINEAR TRIM SOLUTION WITHOUT REDUNDANT CONTROL SURFACES.

                                                      AEROELASTIC TRIM VARIABLES

                                    ID     LABEL              TYPE        TRIM STATUS      VALUE OF UX

                                           INTERCEPT          RIGID BODY          FIXED      1.000000E+00
                                   501     ANGLEA       GENERAL CONTROL            FREE     -1.745191E-01  RADIANS
                                   502     STAB         CONTROL SURFACE            FREE      1.800250E-01  RADIANS
                                   503     URDD3              RIGID BODY          FIXED      1.000000E+00  LOAD FACTOR
                                   505     URDD5              RIGID BODY          FIXED      0.000000E+00  RAD/S/S PER G

                              A E R O S T A T I C   D A T A   R E C O V E R Y   O U T P U T   T A B L E S
                        CONFIGURATION = RAERO        XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
                                          MACH = 4.500000E-01                   Q = 2.000000E+00
                        CHORD = 2.0705E+00            SPAN = 1.1050E+01            AREA = 1.1440E+01

AERODYNAMIC FORCES ON THE AERODYNAMIC ELEMENTS

   GROUP  GRID ID  LABEL       T1                T2                T3                R1                R2                R3
     0        1   EXTA   0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00
     0        2   EXTA   0.000000E+00      0.000000E+00     -1.444136E-02      0.000000E+00      0.000000E+00      0.000000E+00
     0        3   EXTA   0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00
     0        4   EXTA   0.000000E+00      0.000000E+00     -1.199917E-02      0.000000E+00      0.000000E+00      0.000000E+00
     0        5   EXTA   0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00
     0        6   EXTA   0.000000E+00      0.000000E+00     -1.842233E-02      0.000000E+00      0.000000E+00      0.000000E+00
     0        7   EXTA   0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00
     0        8   EXTA   0.000000E+00      0.000000E+00     -7.432471E-03      0.000000E+00      0.000000E+00      0.000000E+00
     0        9   EXTA   0.000000E+00      0.000000E+00     -1.137456E-02      0.000000E+00      0.000000E+00      0.000000E+00
     0       10   EXTA   0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00
     0       11   EXTA   0.000000E+00      0.000000E+00     -2.874870E-02      0.000000E+00      0.000000E+00      0.000000E+00
     0       12   EXTA   0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00
     0       13   EXTA   0.000000E+00      0.000000E+00     -2.808521E-02      0.000000E+00      0.000000E+00      0.000000E+00
     0       14   EXTA   0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00
     0       15   EXTA   0.000000E+00      0.000000E+00     -1.622006E-02      0.000000E+00      0.000000E+00      0.000000E+00
     0       16   EXTA   0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00
     0       17   EXTA   0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00
     0       18   EXTA   0.000000E+00      0.000000E+00      1.453048E-01      0.000000E+00      0.000000E+00      0.000000E+00
     0       19   EXTA   0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00
     0       20   EXTA   0.000000E+00      0.000000E+00     -4.354908E-03      0.000000E+00      0.000000E+00      0.000000E+00
     0       21   EXTA   0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00
     0       22   EXTA   0.000000E+00      0.000000E+00     -1.748004E-02      0.000000E+00      0.000000E+00      0.000000E+00
     0       23   EXTA   0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00
     0       24   EXTA   0.000000E+00      0.000000E+00      1.888480E-02      0.000000E+00      0.000000E+00      0.000000E+00
     0       25   EXTA   0.000000E+00      0.000000E+00     -5.461427E-03      0.000000E+00      0.000000E+00      0.000000E+00
     0       26   EXTA   0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00
     0       27   EXTA   0.000000E+00      0.000000E+00     -1.186515E-02      0.000000E+00      0.000000E+00      0.000000E+00
     0       28   EXTA   0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00
     0       29   EXTA   0.000000E+00      0.000000E+00     -3.980557E-03      0.000000E+00      0.000000E+00      0.000000E+00
     0       30   EXTA   0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00

     0       31   EXTA   0.000000E+00      0.000000E+00      6.722325E-02      0.000000E+00      0.000000E+00      0.000000E+00
     0       32   EXTA   0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00
     0       33   EXTA   0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00
     0       34   EXTA   0.000000E+00      0.000000E+00     -9.144157E-04      0.000000E+00      0.000000E+00      0.000000E+00
     0       35   EXTA   0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00
     0       36   EXTA   0.000000E+00      0.000000E+00      7.818242E-03      0.000000E+00      0.000000E+00      0.000000E+00
     0       37   EXTA   0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00
     0       38   EXTA   0.000000E+00      0.000000E+00      8.865357E-03      0.000000E+00      0.000000E+00      0.000000E+00
     0       39   EXTA   0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00      0.000000E+00
     0       40   EXTA   0.000000E+00      0.000000E+00     -6.701965E-03      0.000000E+00      0.000000E+00      0.000000E+00
     0      101   EXTA   0.000000E+00      0.000000E+00     -3.845994E-04      0.000000E+00      0.000000E+00      0.000000E+00
     0      102   EXTA   0.000000E+00      0.000000E+00     -2.307596E-04      0.000000E+00      0.000000E+00      0.000000E+00
     0      103   EXTA   0.000000E+00      0.000000E+00     -1.915630E-03      0.000000E+00      0.000000E+00      0.000000E+00
     0      104   EXTA   0.000000E+00      0.000000E+00     -1.704221E-02      0.000000E+00      0.000000E+00      0.000000E+00
```

Listing 7-28 Output for Rigid Aerodynamics of Example HA144IR

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*** LABEL NOTATIONS:  LS = LIFTING SURFACE,   ZSB =  Z SLENDER BODY ELEMENT,  YSB =  Y SLENDER BODY ELEMENT,
                                                    ZYSB = ZY SLENDER BODY ELEMENT, EXTA = EXTERNAL AERO.

                                              D I S P L A C E M E N T   V E C T O R

     POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
            1      G      0.0            0.0           -4.414346E-06  -6.408694E-04   5.241443E-05   0.0
            2      G      0.0            0.0           -4.374868E-04  -4.629834E-04  -2.651304E-04   0.0
            3      G      0.0            0.0           -1.278013E-03  -1.677630E-03  -7.734517E-04   0.0
            4      G      0.0            0.0           -2.057938E-03  -8.033858E-04  -1.776961E-03   0.0
            5      G      0.0            0.0           -2.317394E-03  -8.270571E-04  -2.461274E-03   0.0
            6      G      0.0            0.0           -2.001141E-03   1.739034E-04  -3.287011E-03   0.0
            7      G      0.0            0.0           -1.002761E-03   5.063562E-04  -3.576648E-03   0.0
            8      G      0.0            0.0            3.222052E-04   8.703314E-04  -3.874946E-03   0.0
            9      G      0.0            0.0            0.0            0.0            0.0            0.0
           10      G      0.0            0.0           -3.450479E-04  -9.368791E-04  -2.793229E-04   0.0
           11      G      0.0            0.0           -1.061300E-03  -1.079133E-03  -9.299614E-04   0.0
           12      G      0.0            0.0           -1.591319E-03  -9.095234E-04  -1.751859E-03   0.0
           13      G      0.0            0.0           -1.670311E-03  -3.925805E-04  -2.549634E-03   0.0
           14      G      0.0            0.0           -1.144663E-03   1.823932E-04  -3.214812E-03   0.0
           15      G      0.0            0.0           -7.064544E-05   6.723072E-04  -3.602608E-03   0.0
           16      G      0.0            0.0            1.333015E-03   8.765550E-04  -3.847235E-03   0.0
           17      G      0.0            0.0            0.0            0.0            0.0            0.0
           18      G      0.0            0.0           -7.855326E-05  -3.478514E-04  -3.988500E-04   0.0
           19      G      0.0            0.0           -2.513536E-04  -4.114483E-04  -1.146021E-03   0.0
           20      G      0.0            0.0           -1.626649E-04  -1.452033E-04  -1.919672E-03   0.0
           21      G      0.0            0.0            3.617219E-04   2.658343E-04  -2.671381E-03   0.0
           22      G      0.0            0.0            1.371544E-03   6.872019E-04  -3.250707E-03   0.0
           23      G      0.0            0.0            2.759805E-03   9.217162E-04  -3.667990E-03   0.0
           24      G      0.0            0.0            4.303460E-03   9.844918E-04  -3.779152E-03   0.0
           25      G      0.0            0.0            0.0            0.0            0.0            0.0
           26      G      0.0            0.0            2.580694E-04   4.234750E-04  -4.988432E-04   0.0
           27      G      0.0            0.0            7.128000E-04   2.913452E-04  -1.356033E-03   0.0
           28      G      0.0            0.0            1.402407E-03   5.355572E-04  -2.116194E-03   0.0
           29      G      0.0            0.0            2.480115E-03   8.814937E-04  -2.777884E-03   0.0
           30      G      0.0            0.0            3.969781E-03   1.188527E-03  -3.422986E-03   0.0
           31      G      0.0            0.0            5.650163E-03   1.071492E-03  -3.752487E-03   0.0
           32      G      0.0            0.0            7.208862E-03   8.836947E-04  -3.684031E-03   0.0
           33      G      0.0            0.0            1.996776E-05   2.772379E-04  -5.526563E-05   0.0
           34      G      0.0            0.0            4.085872E-04   3.856007E-04  -5.915285E-04   0.0
           35      G      0.0            0.0            1.070788E-03   6.607817E-04  -1.427969E-03   0.0
           36      G      0.0            0.0            1.967397E-03   5.626674E-04  -2.182607E-03   0.0
           37      G      0.0            0.0            3.206751E-03   1.152478E-03  -2.806841E-03   0.0
           38      G      0.0            0.0            4.874127E-03   1.245950E-03  -3.500845E-03   0.0
           39      G      0.0            0.0            6.616813E-03   1.097603E-03  -3.752692E-03   0.0
           40      G      0.0            0.0            8.145548E-03   7.983079E-04  -3.662666E-03   0.0
```

Listing 7-28 Output for Rigid Aerodynamics of Example HA144IR

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 S T R E S S E S   I N   Q U A D R I L A T E R A L   E L E M E N T S   ( Q U A D 4 )
  ELEMENT      FIBER               STRESSES IN ELEMENT COORD SYSTEM             PRINCIPAL STRESSES (ZERO SHEAR)
    ID.      DISTANCE           NORMAL-X       NORMAL-Y      SHEAR-XY       ANGLE         MAJOR           MINOR        VON MISES
0       1  -1.025000E-02     4.653994E+01   2.160081E+01  -3.643636E+01   -35.5538    7.258139E+01   -4.440637E+00   7.490050E+01
            1.025000E-02    -4.653994E+01  -2.160081E+01   3.643636E+01    54.4462    4.440637E+00   -7.258139E+01   7.490050E+01
0       2  -1.025000E-02     7.439899E+01   1.793801E+01  -5.450806E+01   -31.3099    1.075533E+02   -1.521627E+01   1.159129E+02
            1.025000E-02    -7.439899E+01  -1.793801E+01   5.450806E+01    58.6901    1.521627E+01   -1.075533E+02   1.159129E+02
0       3  -1.025000E-02    -9.417421E+01  -8.411938E+00  -6.960816E+01   -60.8173    3.046320E+01   -1.330493E+02   1.506096E+02
            1.025000E-02     9.417421E+01   8.411938E+00   6.960816E+01    29.1827    1.330493E+02   -3.046320E+01   1.506096E+02
0       4  -1.025000E-02    -4.958407E+01   8.453265E+00  -5.431843E+01   -59.0563    4.101849E+01   -8.214930E+01   1.086309E+02
            1.025000E-02     4.958407E+01  -8.453265E+00   5.431843E+01    30.9437    8.214930E+01   -4.101849E+01   1.086309E+02
0       5  -1.025000E-02    -1.212791E+02  -3.056177E+00  -5.006360E+01   -69.8688    1.529545E+01   -1.396307E+02   1.478729E+02
            1.025000E-02     1.212791E+02   3.056177E+00   5.006360E+01    20.1312    1.396307E+02   -1.529545E+01   1.478729E+02
0       6  -1.025000E-02    -5.949134E+01   6.458351E+00  -1.849846E+01   -75.3541    1.129268E+01   -6.432566E+01   7.065214E+01
            1.025000E-02     5.949134E+01  -6.458351E+00   1.849846E+01    14.6459    6.432566E+01   -1.129268E+01   7.065214E+01
0       7  -1.025000E-02    -4.295781E+01   1.403158E+00  -1.901493E+01   -69.6971    8.438108E+00   -4.999276E+01   5.470212E+01
            1.025000E-02     4.295781E+01  -1.403158E+00   1.901493E+01    20.3029    4.999276E+01   -8.438108E+00   5.470212E+01
0       8  -2.050000E-02     1.894946E+02   7.107018E+01  -8.222904E+01   -27.1214    2.316121E+02    2.895273E+01   2.185786E+02
            2.050000E-02    -1.894946E+02  -7.107018E+01   8.222904E+01    62.8786   -2.895273E+01   -2.316121E+02   2.185786E+02
0       9  -2.050000E-02     2.812176E+01   1.262963E+01  -1.381812E+02   -43.3958    1.587738E+02   -1.180224E+02   2.405770E+02
            2.050000E-02    -2.812176E+01  -1.262963E+01   1.381812E+02    46.6042    1.180224E+02   -1.587738E+02   2.405770E+02
0      10  -2.050000E-02    -6.672330E+01  -1.910962E+01  -1.483559E+02   -49.5583    1.073374E+02   -1.931704E+02   2.637623E+02
            2.050000E-02     6.672330E+01   1.910962E+01   1.483559E+02    40.4417    1.931704E+02   -1.073374E+02   2.637623E+02
0      11  -2.050000E-02    -1.343430E+02  -2.999048E+01  -1.387688E+02   -55.3030    6.608689E+01   -2.304204E+02   2.696086E+02
            2.050000E-02     1.343430E+02   2.999048E+01   1.387688E+02    34.6970    2.304204E+02   -6.608689E+01   2.696086E+02
0      12  -2.050000E-02    -1.408012E+02  -2.450376E+01  -1.090364E+02   -59.0354    4.092020E+01   -2.062251E+02   2.294385E+02
            2.050000E-02     1.408012E+02   2.450376E+01   1.090364E+02    30.9646    2.062251E+02   -4.092020E+01   2.294385E+02
0      13  -2.050000E-02    -1.027643E+02  -1.966660E+01  -6.952746E+01   -60.4310    1.978068E+01   -1.422116E+02   1.530636E+02
            2.050000E-02     1.027643E+02   1.966660E+01   6.952746E+01    29.5690    1.422116E+02   -1.978068E+01   1.530636E+02
0      14  -2.050000E-02    -3.475090E+01   1.888198E+00  -3.270432E+01   -59.6278    2.105436E+01   -5.391706E+01   6.697406E+01
            2.050000E-02     3.475090E+01  -1.888198E+00   3.270432E+01    30.3722    5.391706E+01   -2.105436E+01   6.697406E+01
0      15  -2.050000E-02    -8.054434E+00   1.451564E+01  -8.388985E+01   -48.8308    8.787609E+01   -8.141489E+01   1.466459E+02
            2.050000E-02     8.054434E+00  -1.451564E+01   8.388985E+01    41.1692    8.141489E+01   -8.787609E+01   1.466459E+02
0      16  -2.050000E-02     3.065236E+01   2.488188E+01  -1.596773E+02   -44.4824    1.874705E+02   -1.319362E+02   2.780045E+02
            2.050000E-02    -3.065236E+01  -2.488188E+01   1.596773E+02    45.5176    1.319362E+02   -1.874705E+02   2.780045E+02
0      17  -2.050000E-02    -7.917436E+01  -2.847497E+01  -1.417538E+02   -50.0695    9.017789E+01   -1.978272E+02   2.551613E+02
            2.050000E-02     7.917436E+01   2.847497E+01   1.417538E+02    39.9305    1.978272E+02   -9.017789E+01   2.551613E+02
0      18  -2.050000E-02    -1.112264E+02  -2.891084E+01  -1.277698E+02   -53.9275    6.416657E+01   -2.043038E+02   2.428310E+02
            2.050000E-02     1.112264E+02   2.891084E+01   1.277698E+02    36.0725    2.043038E+02   -6.416657E+01   2.428310E+02
0      19  -2.050000E-02    -1.079645E+02  -3.131770E+01  -1.093730E+02   -54.6550    4.625167E+01   -1.855339E+02   2.124695E+02
            2.050000E-02     1.079645E+02   3.131770E+01   1.093730E+02    35.3450    1.855339E+02   -4.625167E+01   2.124695E+02
0      20  -2.050000E-02    -2.260141E+01  -1.699632E+01  -6.966486E+01   -46.1519    4.992234E+01   -8.952007E+01   1.223729E+02
            2.050000E-02     2.260141E+01   1.699632E+01   6.966486E+01    43.8481    8.952007E+01   -4.992234E+01   1.223729E+02
0      21  -2.050000E-02     1.958430E+01   9.778473E+00  -6.406233E+00   -26.2859    2.274851E+01    6.614270E+00   2.026767E+01
            2.050000E-02    -1.958430E+01  -9.778473E+00   6.406233E+00    63.7141   -6.614270E+00   -2.274851E+01   2.026767E+01
0      22  -1.025000E-02    -5.529992E+01  -2.220414E+01  -3.831661E+01   -56.6791    2.985188E+00   -8.048925E+01   8.202260E+01
            1.025000E-02     5.529992E+01   2.220414E+01   3.831661E+01    33.3209    8.048925E+01   -2.985188E+00   8.202260E+01
0      23  -1.025000E-02    -3.415559E+01  -2.670551E+00  -6.513740E+01   -51.7934    4.859968E+01   -8.542582E+01   1.175209E+02
            1.025000E-02     3.415559E+01   2.670551E+00   6.513740E+01    38.2066    8.542582E+01   -4.859968E+01   1.175209E+02
0      24  -1.025000E-02    -2.890074E+01   4.887746E+00  -6.570591E+01   -52.2097    5.583658E+01   -7.984957E+01   1.181194E+02
            1.025000E-02     2.890074E+01  -4.887746E+00   6.570591E+01    37.7903    7.984957E+01   -5.583658E+01   1.181194E+02
0      25  -1.025000E-02    -8.203878E+01  -1.471361E+01  -4.294462E+01   -64.0457    6.189457E+00   -1.029418E+02   1.061720E+02
            1.025000E-02     8.203878E+01   1.471361E+01   4.294462E+01    25.9543    1.029418E+02   -6.189457E+00   1.061720E+02
0      26  -1.025000E-02    -4.440236E+01  -6.668851E-01  -5.293238E+01   -56.2234    3.473696E+01   -7.980621E+01   1.017247E+02
            1.025000E-02     4.440236E+01   6.668851E-01   5.293238E+01    33.7766    7.980621E+01   -3.473696E+01   1.017247E+02
0      27  -1.025000E-02     8.574435E+00   8.326197E-01  -2.402269E+01   -40.4231    2.903609E+01   -1.962903E+01   4.240688E+01
            1.025000E-02    -8.574435E+00  -8.326197E-01   2.402269E+01    49.5769    1.962903E+01   -2.903609E+01   4.240688E+01
0      28  -1.025000E-02     3.692421E+01   1.260206E+01   2.887494E+00     6.6784    3.726230E+01    1.226396E+01   3.289226E+01
            1.025000E-02    -3.692421E+01  -1.260206E+01  -2.887494E+00   -83.3216   -1.226396E+01   -3.726230E+01   3.289226E+01
```

The second input deck is HA144IF, given in Listing 7-29. The deck begins with an assign statement that invokes the database from the rigid run and dblocates the data blocks that will be needed. Case control includes the statement AERCONFIG=RAERO, further identifying the data from the previous run. By default, the value of AECONFIG for this run is AEROSGD and the fact that these two values differ is what triggers the rigid/flexible analysis in the DMAP. It is seen that a SPLINE1 is used in this example and it should be noted that this gives the same result as the SPLINE4 of the previous example. Two CAERO1 entries are now used to define the aerodynamic surfaces that contribute the aeroelastic corrections. It is seen that the CAERO1 that represents the stabilizer has the same geometry as that provided by the AEGRID's in Listing 7-27. The AESURF entry does not have NOLDW in this case since the flexible aerodynamics are being provided by the doublet lattice aerodynamics. ANGLEA is invoked using the AESTAT entry so that the aero created internally is used for the aeroelastic correction. The TRIM task is identical to that of the first run.

Listing 7-29 Input File for Flexible Aerodynamics of Example HA144IF

```
ASSIGN RAERO = 'ha144ir.MASTER'
DBLOCATE DATABLK=(AEUSETS,GDAK,GPAK,GPGK,QKPRESS,ADBQKV0,
            MPJN2O,ADBFJV0,ADBINDX,ADBUXV,ADBWJV,
            SAEMPRK,GDKSK) LOGICAL=RAERO
ID MSC, HA144IF
$$$$$$$$ AEROELASTIC USER'S GUIDE EXAMPLE HA144IF              $$$$$$$$
$                                                                     $
$       MODEL DESCRIPTION       MODEL A OF NASA TN D-1824             $
$                               HALF SPAN 15 DEGREE SWEPT WING        $
$                               28 QUAD4 PANEL MODEL                  $
$                                                                     $
$                                                                     $
$       SOLUTION                RIGID AERODYNAMICS ARE INPUT          $
$                               FROM HA144IR,  FLEXIBLE INCREMENT IS  $
$                               PROVIDED FROM A DOUBLET LATTICE MODEL $
$                                                                     $
$$$$$$$$                                                       $$$$$$$$TIME 5 $ CPU TIME IN MINUTES
DIAG 8
SOL 144  $ STATIC AERO
CEND
TITLE = EXAMPLE HA144IF: HALF SPAN 15-DEG SWEPT UNTAPERED WING
SUBT  = FREE SYMMETRIC STRUCTURE
LABEL = 0.041 IN PLATE W/BEVELLED LEADING AND TRAILING EDGES
  AERCONFIG = RAERO
  ECHO   = BOTH
  SPC    = 1
  DISP   = ALL
  STRESS = ALL
  FORCE  = ALL
  AEROF  = ALL
  APRES  = ALL
  TRIM = 1
  TRIMF(RIGID,INERTIA,AIR,APPLIED) = ALL
$
BEGIN BULK
$*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$

$                                                                      $
$        THE ANNOTATIONS IN THIS INPUT DECK ARE INTENDED TO            $
$        EXPLAIN THE DATA ON THE CARD IMAGES FOR THIS                  $
$        EXAMPLE WITHOUT REFERENCE TO THE VARIOUS MANUALS WHERE        $
$        MORE GENERAL DESCRIPTIONS WILL BE FOUND.                      $
$                                                                      $
$*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
INCLUDE 'PLATEST.DAT'
$                                                                      $
$                                                                      $
$        THE RBAR ENTRY DEFINES A RIGID BAR WITH SIX DEGREES OF        $
$        FREEDOM AT EACH END.  LISTED ARE THE GRID POINT NUMBERS,      $
$        THE INDEPENDENT AND THE DEPENDENT DOFS AT THE TWO ENDS.       $
$                                                                      $
$       EID     GA      GB      CNA     CNB     CMA     CMB            $
RBAR    101     17      9       123456
RBAR    102     17      25      123456
$                                                                      $
$                 * * MASS AND INERTIA PROPERTIES * *                  $
$                                                                      $
$        THE MAT1 ENTRY DEFINES THE MATERIAL PROPERTIES FOR LINEAR,    $
$        TEMPERATURE-INDEPENDENT, ISOTROPIC MATERIALS.  IT LISTS       $
$        YOUNGS MODULUS, THE SHEAR MODULUS, POISSONS RATIO MASS        $
$        DENSITY, THERMAL EXPANSION COEFFICIENT AND STRUCTURAL         $
$        ELEMENT DAMPING.                                              $
$                                                                      $
$       MID     E       G       NU      RHO     A       TREF    GE
MAT1    1       10.3+6  3.9+6           0.1
$                                                                      $
$                                                                      $
PARAM   AUNITS  .0025901
$                                                                      $
```

Listing 7-29 Input File for Flexible Aerodynamics of Example HA144IF

```
$                    * * STRUCTURAL CONSTRAINTS * *                     $
$                                                                       $
$        THE SUPORT ENTRY IDENTIFIES A DOF IN WHICH THE USER DESIRES    $
$        DETERMINATE REACTIONS TO BE APPLIED TO PREVENT RIGID BODY      $
$        MOTION. IT INVOKES THE SOLUTION OF THE BALANCE EQUATIONS TO    $
$        DETERMINE THE REACTIONS.  IN THE STATIC AEROELASTIC SOLUTION   $
$        THE DOF COMPONENTS MUST BE CONSISTENT WITH THE UNDEFINED       $
$        VARIABLES ON THE TRIM ENTRIES.  IT IS ALSO IMPORTANT THAT      $
$        NO OTHER POINT ON THE STRUCTURE BE CONSTRAINED IN THESE        $
$        DOFS; OTHERWISE, UNDETERMINED CONSTRAINT FORCES WILL BE        $
$        IMPOSED AND THE REACTIONS AT THE SUPORT POINT WILL NOT         $
$        BE THE TOTAL OF THE REACTION FORCES.                           $
$                                                                       $
$       ID      C                                                       $
SUPORT  17      35
$                                                                       $
$        THE SPC1 ENTRY DEFINES SETS OF SINGLE-POINT CONSTRAINTS.       $
$        IT LISTS ITS ID, THE DOF COMPONENTS TO BE CONSTRAINED          $
$        AND THE GRID POINT NO.                                         $
$                                                                       $
$       SID     C       G1      G2      ETC.
SPC1    1       1246    17
SPC1    1       6       1       THRU    8
SPC1    1       6       10      THRU    16
SPC1    1       6       18      THRU    24
SPC1    1       6       26      THRU    40
$                                                                       $
$                                                                       $
$                    * * * AERODYNAMIC DATA * * *                       $
$                                                                       $
$                         (LB-IN-SEC SYSTEM)                            $
$                                                                       $
$                      * * ELEMENT GEOMETRY * *                         $
$                                                                       $
$        THE AEROS ENTRY IS UNIQUE TO THE STATIC AEROELASTICITY         $
$        SOLUTION, SOL21.  ACSID IDENTIFIES THE AERO COORDINATE         $
$        SYSTEM.  RCSID IDENTIFIES THE REFERENCE COORDINATE SYS-        $
$        TEM FOR RIGID BODY MOTION.  REFC IS THE REFERENCE CHORD.       $
$        REFB IS THE REFERENCE SPAN (NOT THE SEMI-SPAN).  REFS IS       $
$        THE REFERENCE WING AREA (FOR ONE SIDE ONLY, IN THIS CASE).     $
$        SYMXZ AND SYMXY ARE SYMMETRY KEYS THAT SPECIFY THE             $
$        PRESENCE OF REFLECTION PLANES ONLY, NOT THE EXISTENCE OF       $
$        OTHER LIFTING SURFACES.                                        $
$                                                                       $
$       ACSID   RCSID   REFC    REFB    REFS    SYMXZ   SYMXY
AEROS   0       11      2.07055 11.0502 11.4400 1
$                                                                       $
$        THIS CORD2R ENTRY DEFINES THE AERO COORDINATE SYSTEM           $
$        FLAGGED BY THE AEROS ENTRY.  THE ORIGIN IS AT THE WING         $
$        SUPPORT POINT (GRID 17).  LISTED ARE THE ORIGIN, A POINT       $
$        ON THE Z-AXIS AND A POINT ON THE X-AXIS, ALL IN THE RID        $
$        COORDINATE SYSTEM.                                             $
$                                                                       $
$       CID     RID     A1      A2      A3      B1      B2      B3
CORD2R  11              1.035275 0.0    0.0     1.035275 0.0    1.0     +CORD1
$       C1      C2      C3
+CORD1  2.0     0.0     0.0
CORD2R  1018.50.00.08.50.01.0
9.00.00.0
$                                                                       $
$        THE CAERO1 ENTRY IS USED FOR DOUBLET LATTICE AERODYNAMICS.     $
$        LISTED ARE ITS PAERO ENTRY ID AND THE COORDINATE SYSTEM        $
$        FOR LOCATING THE INBOARD AND OUTBOARD LEADING EDGE POINTS      $
$        (1 AND 4).  NSPAN AND NCHORD, OR LSPAN AND LCHORD, ARE         $
$        USED TO PARTITION THE WING INTO AERODYNAMIC PANELS.            $
$        THE FORMER FOR UNIFORMLY SPACED PANELS AND THE LATTER          $
$        FOR NON-UNIFORMLY SPACED PANELS.  IGID IS THE ID OF ITS        $
$        ASSOCIATED INTERFERENCE GROUP.  THE CONTINUATION ENTRY         $
$        DEFINES POINTS 1 AND 4, THE ROOT CHORD AND TIP CHORD.          $
$        THE BOXES FORMED BY THE GRID LINES WILL BE NUMBERED            $
$        BEGINNING WITH EID SO CHOOSE A NUMBER THAT IS UNIQUE,          $
$        AND IS GREATER THAN ALL STRUCTURAL GRID, SCALAR AND            $
$        EXTRA POINT IDS.                                               $
$                                                                       $
$       EID     PID     CP      NSPAN   NCHORD  LSPAN   LCHORD  IGID
CAERO1  101     1       0       6       4                       1       +CA101
$      ( FWD LEFT POINT  )   ROOTCHORD ( FWD RIGHT POINT  )  TIP CHORD
$       X1      Y1      Z1      X12     X4        Y4    Z4      X14
+CA101  .0      .0      .0      2.07055 1.48044 5.52510 0.0     2.07055
CAERO12011211
8.00.00.01.08.02.50.01.0
SPLINRB 201     201     50517123456
AELIST505201202
$                                                                       $
```

Listing 7-29 Input File for Flexible Aerodynamics of Example HA144IF

```
$        THE PAERO1 ENTRY IS REQUIRED EVEN THOUGH IT IS NON-FUNCTIONAL  $
$        (BECAUSE THERE ARE NO ASSOCIATED BODIES IN THIS EXAMPLE).      $
$                                                                       $
$       PID     B1      B2      B3      B4      B5      B6
PAERO1  1
$
$                 * SURFACE SPLINE FIT ON THE WING *                    $
$                                                                       $
$        THE SPLINE1 ENTRY DEFINES A SURFACE SPLINE FOR INTERPO-        $
$        LATING OUT-OF-PLANE DISPLACEMENTS FROM THE STRUCTURAL          $
$        GRID POINTS ON THE SETG ENTRY TO THE SUB-REGION DEFINED        $
$        BY AERODYNAMIC BOXES 101 THRU 124 OF THE REGION ON THE         $
$        CAERO1 ENTRY.  DZ=0 SPECIFIES THAT NO SMOOTHING OF THE         $
$        SPLINE IS TO BE IMPOSED.                                       $
$                                                                       $
$       EID     CAERO   BOX1    BOX2    SETG    DZ
SPLINE1 100     101     101     124     100     .0
$                                                                       $
$        THE SET1 ENTRY DEFINES THE STRUCTURAL GRID POINTS TO           $
$        BE USED BY THE SURFACE SPLINE FOR INTERPOLATION.               $
$                                                                       $
$       SID     G1      G2      G3      G4      G5      G6
SET1    100     2       4       6       8       9       11      13      +S1
+S1     15      18      20      22      24      25      27      29      +S2
+S2     31      34      36      38      40
$                                                                       $


$              * * * STATIC AEROELASTIC SOLUTION * * *                  $
$                                                                       $
$                      * * AERODYNAMIC DOFS * *                         $
$                                                                       $
$        THE AESTAT ENTRY LISTS TRIM VARIABLES USED TO SPECIFY          $
$        RIGID BODY MOTIONS.  THESE AND THE CONTROL SURFACE             $
$        ROTATIONS MAKE UP THE VARIABLES IN THE EQUATIONS OF            $
$        MOTION.                                                        $
$                                                                       $
AESTAT  501     ANGLEA
AESTAT  503     URDD3
AESTAT  504     URDD5
AESURF502STAB101505
$                                                                       $
$                      * * TRIM CONDITIONS * *                          $
$                                                                       $
$        THE TRIM ENTRY SPECIFIES CONSTRAINTS FOR THE TRIM VARIABLES    $
$        LISTED ON THE AESTAT AND AESURF ENTRIES.  LISTED ARE ITS ID,   $
$        THE MACH NUMBER, DYNAMIC PRESSURE AND PAIRS OF TRIM VARI-      $
$        ABLES AND THEIR CONSTRAINED VALUES.  THOSE THAT ARE NOT        $
$        HELD FIXED MUST BE CONSTRAINED BY REACTION FORCES STIPU-       $
$        LATED ON THE SUPORT ENTRY.                                     $
$                                                                       $
TRIM    1       0.45    2.0     URDD3   1.0     URDD5   0.0
ENDDATA
```

Selected results are shown in Listing 7-30. It is now seen that the elastic stability derivatives do not match the rigid derivatives. Notably, the lift curve slope has a rigid value of 5.30 while the flexible value is 4.85, indicating that the wing has washed-out. Trim, static deflection and stress results are shown in the listing, duplicating the items provided in Listing 7-28. The trim condition has changed slightly to -9.90 degrees angle of attack and a 10.0 degrees for the stabilizer setting.

Listing 7-30 Selected Output for Flexible Aerodynamics of Example HA144IF

```
N O N - D I M E N S I O N A L   S T A B I L I T Y   A N D   C O N T R O L   D E R I V A T I V E   C O E F F I C I E N T S

                     CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
                                     MACH = 4.5000E-01                    Q = 2.0000E+00
                     CHORD = 2.0705E+00           SPAN = 1.1050E+01            AREA = 1.1440E+01


            TRANSFORMATION FROM BASIC TO REFERENCE COORDINATES:

          { X }          [  1.0000    0.0000    0.0000  ]  { X }          {-1.0353E+00 }
          { Y }    =     [  0.0000    1.0000    0.0000  ]  { Y }      +   { 0.0000E+00 }
          { Z }REF       [  0.0000    0.0000    1.0000  ]  { Z }BAS       { 0.0000E+00 }


CONTROLLER STATE: INTERCEPT ONLY, ALL CONTROLLERS ARE ZERO

TRIM VARIABLE   COEFFICIENT           RIGID                        ELASTIC                             INERTIAL
                           UNSPLINED        SPLINED       RESTRAINED      UNRESTRAINED      RESTRAINED       UNRESTRAINED

REF. COEFF.      CX         0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                 CY         0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                 CZ         7.396853E-01    7.396853E-01    6.565406E-01    1.371549E+01     0.000000E+00    1.371549E+01
                 CMX        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                 CMY        9.123180E-02    9.123180E-02   -2.870717E-03   -2.518213E+00     0.000000E+00   -2.518213E+00
                 CMZ        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00


ANGLEA           CX         0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                 CY         0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                 CZ         5.302972E+00    5.302972E+00    4.845831E+00    4.057575E+01     0.000000E+00    4.057575E+01
                 CMX        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                 CMY       -3.038611E+00   -3.038611E+00   -3.494994E+00   -7.714505E+00     0.000000E+00   -7.714505E+00
                 CMZ        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00

STAB             CX         0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                 CY         0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                 CZ         1.041958E+00    1.041958E+00    1.042106E+00   -3.860268E+01     0.000000E+00   -3.860268E+01
                 CMX        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                 CMY       -3.456013E+00   -3.456013E+00   -3.458249E+00    6.824928E+00     0.000000E+00    6.824928E+00
                 CMZ        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00

URDD3            CX         0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                 CY         0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                 CZ         0.000000E+00    0.000000E+00    6.234590E-04    0.000000E+00     1.793749E-03    0.000000E+00
                 CMX        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                 CMY        0.000000E+00    0.000000E+00    1.762298E-03    0.000000E+00    -6.412642E-04    0.000000E+00
                 CMZ        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00

URDD5            CX         0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                 CY         0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                 CZ         0.000000E+00    0.000000E+00   -8.571407E-04    0.000000E+00    -1.327770E-03    0.000000E+00
                 CMX        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
                 CMY        0.000000E+00    0.000000E+00   -2.682717E-03    0.000000E+00     8.747027E-04    0.000000E+00
                 CMZ        0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00     0.000000E+00    0.000000E+00
N O N - D I M E N S I O N A L   H I N G E   M O M E N T   D E R I V A T I V E   C O E F F I C I E N T S


                     CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
                                     MACH = 4.5000E-01                    Q = 2.0000E+00

      CONTROL SURFACE = STAB         REFERENCE CHORD LENGTH =  1.000000E+00     REFERENCE AREA =  1.000000E+00

          TRIM VARIABLE            RIGID                            ELASTIC                            INERTIAL
                                                         RESTRAINED     UNRESTRAINED          RESTRAINED      UNRESTRAINED
          AT REFERENCE        6.548002E+01               6.555858E+01    6.673172E+01         0.000000E+00    0.000000E+00
          ANGLEA              3.781791E+02               3.785545E+02    3.794778E+02         0.000000E+00    0.000000E+00
          STAB                3.626615E+00               3.628414E+00   -2.206102E+00         0.000000E+00    0.000000E+00
          URDD3               0.000000E+00              -1.572965E-03    0.000000E+00         0.000000E+00    0.000000E+00
          URDD5               0.000000E+00               2.403356E-03    0.000000E+00         0.000000E+00    0.000000E+00

                           A E R O S T A T I C   D A T A   R E C O V E R Y   O U T P U T   T A B L E S
                     CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
                                       MACH = 4.500000E-01                Q = 2.000000E+00
                     CHORD = 2.0705E+00           SPAN = 1.1050E+01            AREA = 1.1440E+01

      TRIM ALGORITHM USED: LINEAR TRIM SOLUTION WITHOUT REDUNDANT CONTROL SURFACES.
```

Listing 7-30 Selected Output for Flexible Aerodynamics of Example HA144IF

```
                                        AEROELASTIC TRIM VARIABLES

                 ID      LABEL                  TYPE        TRIM STATUS      VALUE OF UX

                         INTERCEPT          RIGID BODY           FIXED      1.000000E+00
                501      ANGLEA             RIGID BODY            FREE     -1.727629E-01  RADIANS
                502      STAB          CONTROL SURFACE            FREE      1.744634E-01  RADIANS
                503      URDD3              RIGID BODY           FIXED      1.000000E+00  LOAD FACTOR
                504      URDD5              RIGID BODY           FIXED      0.000000E+00  RAD/S/S PER G

                              AERODYNAMIC PRESSURES ON THE AERODYNAMIC ELEMENTS

                                         AERODYNAMIC PRES.        AERODYNAMIC
                         GRID   LABEL       COEFFICIENTS           PRESSURES
                           1      LS        -7.614257E-03        -1.522851E-02
                           2      LS        -3.115213E-03        -6.230426E-03
                           3      LS        -3.509939E-03        -7.019878E-03
                           4      LS        -4.227365E-03        -8.454730E-03
                           5      LS        -1.039317E-02        -2.078634E-02
                           6      LS        -5.355796E-03        -1.071159E-02
                           7      LS        -4.603414E-03        -9.206828E-03
                           8      LS        -3.621564E-03        -7.243128E-03
                           9      LS        -1.519606E-02        -3.039212E-02
                          10      LS        -7.672169E-03        -1.534434E-02
                          11      LS        -5.510556E-03        -1.102111E-02
                          12      LS        -3.440117E-03        -6.880234E-03
                          13      LS        -2.012178E-02        -4.024356E-02
                          14      LS        -9.752771E-03        -1.950554E-02
                          15      LS        -5.911650E-03        -1.182330E-02
                          16      LS        -3.180421E-03        -6.360842E-03
                          17      LS        -2.416047E-02        -4.832094E-02
                          18      LS        -1.010465E-02        -2.020929E-02
                          19      LS        -5.113824E-03        -1.022765E-02
                          20      LS        -2.098267E-03        -4.196533E-03
                          21      LS        -2.253143E-02        -4.506287E-02
                          22      LS        -7.884782E-03        -1.576956E-02
                          23      LS        -3.161187E-03        -6.322373E-03
                          24      LS        -6.773976E-04        -1.354795E-03
                          25      LS         6.264235E-03         1.252847E-02
                          26      LS         3.359033E-02         6.718067E-02

*** LABEL NOTATIONS:  LS = LIFTING SURFACE,   ZIB = Z INTERFERENCE BODY ELEMENT,  ZSB = Z SLENDER BODY ELEMENT,
                                              YIB = Y INTERFERENCE BODY ELEMENT,  YSB = Y SLENDER BODY ELEMENT.

AERODYNAMIC FORCES ON THE AERODYNAMIC ELEMENTS

 GROUP  GRID ID  LABEL       T1                T2                T3                R1                R2                R3
    1      101    LS    0.000000E+00      0.000000E+00     -7.258922E-03      0.000000E+00     -9.393726E-04      0.000000E+00
    1      102    LS    0.000000E+00      0.000000E+00     -2.969835E-03      0.000000E+00     -3.843245E-04      0.000000E+00
    1      103    LS    0.000000E+00      0.000000E+00     -3.346141E-03      0.000000E+00     -4.330220E-04      0.000000E+00
    1      104    LS    0.000000E+00      0.000000E+00     -4.030086E-03      0.000000E+00     -5.215310E-04      0.000000E+00
    1      105    LS    0.000000E+00      0.000000E+00     -9.908154E-03      0.000000E+00     -1.282208E-03      0.000000E+00
    1      106    LS    0.000000E+00      0.000000E+00     -5.105857E-03      0.000000E+00     -6.607457E-04      0.000000E+00
    1      107    LS    0.000000E+00      0.000000E+00     -4.388586E-03      0.000000E+00     -5.679242E-04      0.000000E+00
    1      108    LS    0.000000E+00      0.000000E+00     -3.452556E-03      0.000000E+00     -4.467932E-04      0.000000E+00
    1      109    LS    0.000000E+00      0.000000E+00     -1.448690E-02      0.000000E+00     -1.874741E-03      0.000000E+00
    1      110    LS    0.000000E+00      0.000000E+00     -7.314132E-03      0.000000E+00     -9.465172E-04      0.000000E+00
    1      111    LS    0.000000E+00      0.000000E+00     -5.253395E-03      0.000000E+00     -6.798386E-04      0.000000E+00
    1      112    LS    0.000000E+00      0.000000E+00     -3.279577E-03      0.000000E+00     -4.244080E-04      0.000000E+00
    1      113    LS    0.000000E+00      0.000000E+00     -1.918276E-02      0.000000E+00     -2.482429E-03      0.000000E+00
    1      114    LS    0.000000E+00      0.000000E+00     -9.297638E-03      0.000000E+00     -1.203202E-03      0.000000E+00
    1      115    LS    0.000000E+00      0.000000E+00     -5.635771E-03      0.000000E+00     -7.293215E-04      0.000000E+00
    1      116    LS    0.000000E+00      0.000000E+00     -3.032000E-03      0.000000E+00     -3.923693E-04      0.000000E+00
    1      117    LS    0.000000E+00      0.000000E+00     -2.303297E-02      0.000000E+00     -2.980683E-03      0.000000E+00
    1      118    LS    0.000000E+00      0.000000E+00     -9.633094E-03      0.000000E+00     -1.246613E-03      0.000000E+00
    1      119    LS    0.000000E+00      0.000000E+00     -4.875177E-03      0.000000E+00     -6.308937E-04      0.000000E+00
    1      120    LS    0.000000E+00      0.000000E+00     -2.000347E-03      0.000000E+00     -2.588636E-04      0.000000E+00
    1      121    LS    0.000000E+00      0.000000E+00     -2.147996E-02      0.000000E+00     -2.779708E-03      0.000000E+00
    1      122    LS    0.000000E+00      0.000000E+00     -7.516823E-03      0.000000E+00     -9.727473E-04      0.000000E+00
    1      123    LS    0.000000E+00      0.000000E+00     -3.013663E-03      0.000000E+00     -3.899963E-04      0.000000E+00
    1      124    LS    0.000000E+00      0.000000E+00     -6.457855E-04      0.000000E+00     -8.357069E-05      0.000000E+00
    1      201    LS    0.000000E+00      0.000000E+00      1.566059E-02      0.000000E+00      3.915147E-03      0.000000E+00
    1      202    LS    0.000000E+00      0.000000E+00      8.397583E-02      0.000000E+00      2.099396E-02      0.000000E+00
```

Listing 7-30 Selected Output for Flexible Aerodynamics of Example HA144IF

```
 *** LABEL NOTATIONS:  LS = LIFTING SURFACE,   ZSB =  Z SLENDER BODY ELEMENT,  YSB =  Y SLENDER BODY ELEMENT,
                                              ZYSB = ZY SLENDER BODY ELEMENT, EXTA = EXTERNAL AERO.

                                         D I S P L A C E M E N T   V E C T O R

POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
       1      G      0.0            0.0            5.486813E-06  -5.297510E-04   7.816125E-05   0.0
       2      G      0.0            0.0           -5.601728E-04  -8.612636E-04   1.258721E-05   0.0
       3      G      0.0            0.0           -2.103089E-03  -2.831849E-03  -2.746916E-04   0.0
       4      G      0.0            0.0           -4.221082E-03  -2.693576E-03  -1.202171E-03   0.0
       5      G      0.0            0.0           -6.275403E-03  -3.136858E-03  -1.960470E-03   0.0
       6      G      0.0            0.0           -8.007711E-03  -2.403049E-03  -2.891499E-03   0.0
       7      G      0.0            0.0           -9.139274E-03  -2.091406E-03  -3.254147E-03   0.0
       8      G      0.0            0.0           -9.947687E-03  -1.765637E-03  -3.610066E-03   0.0
       9      G      0.0            0.0            0.0            0.0            0.0            0.0
      10      G      0.0            0.0           -5.396802E-04  -1.379356E-03  -7.393925E-05   0.0
      11      G      0.0            0.0           -2.010003E-03  -2.346868E-03  -4.720207E-04   0.0
      12      G      0.0            0.0           -3.897898E-03  -2.794471E-03  -1.256267E-03   0.0
      13      G      0.0            0.0           -5.753173E-03  -2.716191E-03  -2.089885E-03   0.0
      14      G      0.0            0.0           -7.249236E-03  -2.360726E-03  -2.835148E-03   0.0
      15      G      0.0            0.0           -8.288716E-03  -1.935940E-03  -3.293259E-03   0.0
      16      G      0.0            0.0           -9.002033E-03  -1.720282E-03  -3.578963E-03   0.0
      17      G      0.0            0.0            0.0            0.0            0.0            0.0
      18      G      0.0            0.0           -4.021225E-04  -1.117097E-03  -2.663550E-04   0.0
      19      G      0.0            0.0           -1.481611E-03  -1.813941E-03  -8.817545E-04   0.0
      20      G      0.0            0.0           -2.792352E-03  -2.100099E-03  -1.587405E-03   0.0
      21      G      0.0            0.0           -4.035118E-03  -2.045826E-03  -2.326788E-03   0.0
      22      G      0.0            0.0           -5.005419E-03  -1.814751E-03  -2.931420E-03   0.0
      23      G      0.0            0.0           -5.688871E-03  -1.649072E-03  -3.383896E-03   0.0
      24      G      0.0            0.0           -6.240872E-03  -1.602306E-03  -3.508168E-03   0.0
      25      G      0.0            0.0            0.0            0.0            0.0            0.0
      26      G      0.0            0.0           -1.129999E-04  -5.061722E-04  -5.131198E-04   0.0
      27      G      0.0            0.0           -6.626597E-04  -1.279381E-03  -1.250866E-03   0.0
      28      G      0.0            0.0           -1.443054E-03  -1.505460E-03  -1.898050E-03   0.0
      29      G      0.0            0.0           -2.154232E-03  -1.453487E-03  -2.515127E-03   0.0
      30      G      0.0            0.0           -2.637850E-03  -1.310331E-03  -3.151146E-03   0.0
      31      G      0.0            0.0           -3.015734E-03  -1.485348E-03  -3.478897E-03   0.0
      32      G      0.0            0.0           -3.539817E-03  -1.692246E-03  -3.429623E-03   0.0
      33      G      0.0            0.0            4.345939E-05   7.196162E-05  -1.842941E-04   0.0
      34      G      0.0            0.0            4.215485E-05  -4.814089E-04  -6.516634E-04   0.0
      35      G      0.0            0.0           -3.256193E-04  -1.054646E-03  -1.372202E-03   0.0
      36      G      0.0            0.0           -9.325981E-04  -1.445814E-03  -1.991640E-03   0.0
      37      G      0.0            0.0           -1.492960E-03  -1.252937E-03  -2.565666E-03   0.0
      38      G      0.0            0.0           -1.802768E-03  -1.206387E-03  -3.239755E-03   0.0
      39      G      0.0            0.0           -2.119436E-03  -1.512819E-03  -3.482693E-03   0.0
      40      G      0.0            0.0           -2.667830E-03  -1.711850E-03  -3.407182E-03   0.0
```

Listing 7-30 Selected Output for Flexible Aerodynamics of Example HA144IF

```
                             S T R E S S E S   I N   Q U A D R I L A T E R A L   E L E M E N T S   ( Q U A D 4 )
  ELEMENT      FIBER               STRESSES IN ELEMENT COORD SYSTEM             PRINCIPAL STRESSES (ZERO SHEAR)
    ID.      DISTANCE           NORMAL-X       NORMAL-Y      SHEAR-XY       ANGLE         MAJOR           MINOR        VON MISES
0       1  -1.025000E-02     1.094667E+02   1.043138E+01  -2.677544E+01   -14.2006    1.162422E+02    3.655852E+00   1.144581E+02
            1.025000E-02    -1.094667E+02  -1.043138E+01   2.677544E+01    75.7994   -3.655852E+00   -1.162422E+02   1.144581E+02
0       2  -1.025000E-02     1.814989E+02   1.981946E+01  -5.187591E+01   -16.3444    1.967121E+02    4.606228E+00   1.944499E+02
            1.025000E-02    -1.814989E+02  -1.981946E+01   5.187591E+01    73.6556   -4.606228E+00   -1.967121E+02   1.944499E+02
0       3  -1.025000E-02    -6.963681E+00  -7.167293E+00  -7.639600E+01   -44.9618    6.933058E+01   -8.346155E+01   1.325104E+02
            1.025000E-02     6.963681E+00   7.167293E+00   7.639600E+01    45.0382    8.346155E+01   -6.933058E+01   1.325104E+02
0       4  -1.025000E-02     1.824953E+00   4.735553E+00  -6.816471E+01   -45.6115    7.146050E+01   -6.489999E+01   1.181372E+02
            1.025000E-02    -1.824953E+00  -4.735553E+00   6.816471E+01    44.3885    6.489999E+01   -7.146050E+01   1.181372E+02
0       5  -1.025000E-02    -9.217455E+01   2.694756E-01  -6.243366E+01   -63.2570    3.172910E+01   -1.236342E+02   1.421793E+02
            1.025000E-02     9.217455E+01  -2.694756E-01   6.243366E+01    26.7430    1.236342E+02   -3.172910E+01   1.421793E+02
0       6  -1.025000E-02    -5.654527E+01   5.143700E+00  -2.504171E+01   -70.4639    1.402917E+01   -6.543075E+01   7.345706E+01
            1.025000E-02     5.654527E+01  -5.143700E+00   2.504171E+01    19.5361    6.543075E+01   -1.402917E+01   7.345706E+01
0       7  -1.025000E-02    -4.222565E+01   2.682850E+00  -2.395075E+01   -66.5765    1.305895E+01   -5.260175E+01   6.020302E+01
            1.025000E-02     4.222565E+01  -2.682850E+00   2.395075E+01    23.4235    5.260175E+01   -1.305895E+01   6.020302E+01
0       8  -2.050000E-02     3.605385E+02   1.064491E+02  -6.509226E+01   -13.5643    3.762431E+02    9.074447E+01   3.400756E+02
            2.050000E-02    -3.605385E+02  -1.064491E+02   6.509226E+01    76.4357   -9.074447E+01   -3.762431E+02   3.400756E+02
0       9  -2.050000E-02     2.235521E+02   2.622042E+01  -1.151394E+02   -24.7030    2.765175E+02   -2.674500E+01   2.908138E+02
            2.050000E-02    -2.235521E+02  -2.622042E+01   1.151394E+02    65.2970    2.674500E+01   -2.765175E+02   2.908138E+02
0      10  -2.050000E-02     8.482401E+01  -2.283036E+01  -1.486694E+02   -35.0484    1.891105E+02   -1.271169E+02   2.756096E+02
            2.050000E-02    -8.482401E+01   2.283036E+01   1.486694E+02    54.9516    1.271169E+02   -1.891105E+02   2.756096E+02
0      11  -2.050000E-02    -3.214412E+01  -3.444434E+01  -1.479842E+02   -44.7774    1.146945E+02   -1.812829E+02   2.584772E+02
            2.050000E-02     3.214412E+01   3.444434E+01   1.479842E+02    45.2226    1.812829E+02   -1.146945E+02   2.584772E+02
0      12  -2.050000E-02    -8.876827E+01  -2.814444E+01  -1.227769E+02   -51.9341    6.800702E+01   -1.849197E+02   2.267071E+02
            2.050000E-02     8.876827E+01   2.814444E+01   1.227769E+02    38.0659    1.849197E+02   -6.800702E+01   2.267071E+02
0      13  -2.050000E-02    -8.645687E+01  -2.252306E+01  -8.076780E+01   -55.7965    3.237384E+01   -1.413538E+02   1.600160E+02
            2.050000E-02     8.645687E+01   2.252306E+01   8.076780E+01    34.2035    1.413538E+02   -3.237384E+01   1.600160E+02
0      14  -2.050000E-02    -3.463584E+01   7.142648E-01  -3.795633E+01   -57.4849    2.490914E+01   -5.883072E+01   7.447779E+01
            2.050000E-02     3.463584E+01  -7.142648E-01   3.795633E+01    32.5151    5.883072E+01   -2.490914E+01   7.447779E+01
0      15  -2.050000E-02     2.325406E+02   7.037858E+01  -9.309010E+01   -24.4722    2.749095E+02    2.800960E+01   2.620299E+02
            2.050000E-02    -2.325406E+02  -7.037858E+01   9.309010E+01    65.5278   -2.800960E+01   -2.749095E+02   2.620299E+02
0      16  -2.050000E-02     1.987726E+02   2.878582E+01  -1.476968E+02   -30.0407    2.841853E+02   -5.662688E+01   3.163233E+02
            2.050000E-02    -1.987726E+02  -2.878582E+01   1.476968E+02    59.9593    5.662688E+01   -2.841853E+02   3.163233E+02
0      17  -2.050000E-02     5.441123E+01  -2.905441E+01  -1.336654E+02   -36.3303    1.527072E+02   -1.273504E+02   2.428682E+02
            2.050000E-02    -5.441123E+01   2.905441E+01   1.336654E+02    53.6697    1.273504E+02   -1.527072E+02   2.428682E+02
0      18  -2.050000E-02    -2.669641E+01  -3.042488E+01  -1.282692E+02   -44.5837    9.972209E+01   -1.568434E+02   2.240203E+02
            2.050000E-02     2.669641E+01   3.042488E+01   1.282692E+02    45.4163    1.568434E+02   -9.972209E+01   2.240203E+02
0      19  -2.050000E-02    -6.264007E+01  -3.387819E+01  -1.140588E+02   -48.5931    6.670275E+01   -1.632210E+02   2.048845E+02
            2.050000E-02     6.264007E+01   3.387819E+01   1.140588E+02    41.4069    1.632210E+02   -6.670275E+01   2.048845E+02
0      20  -2.050000E-02    -6.664499E+00  -1.865156E+01  -7.399231E+01   -42.6845    6.157663E+01   -8.689269E+01   1.291998E+02
            2.050000E-02     6.664499E+00   1.865156E+01   7.399231E+01    47.3155    8.689269E+01   -6.157663E+01   1.291998E+02
0      21  -2.050000E-02     2.368680E+01   8.498116E+00  -9.805430E+00   -26.1210    2.849490E+01    3.690020E+00   2.684080E+01
            2.050000E-02    -2.368680E+01  -8.498116E+00   9.805430E+00    63.8790   -3.690020E+00   -2.849490E+01   2.684080E+01
0      22  -1.025000E-02     4.355925E+01  -2.839675E+01  -4.745959E+01   -26.4175    6.713651E+01   -5.197401E+01   1.034310E+02
            1.025000E-02    -4.355925E+01   2.839675E+01   4.745959E+01    63.5825    5.197401E+01   -6.713651E+01   1.034310E+02
0      23  -1.025000E-02     6.663266E+01   7.952997E+00  -7.239833E+01   -33.9697    1.154103E+02   -4.082467E+01   1.403488E+02
            1.025000E-02    -6.663266E+01  -7.952997E+00   7.239833E+01    56.0303    4.082467E+01   -1.154103E+02   1.403488E+02
0      24  -1.025000E-02     2.061796E+01  -1.505704E+00  -6.155776E+01   -39.9064    7.209989E+01   -5.298764E+01   1.087497E+02
            1.025000E-02    -2.061796E+01   1.505704E+00   6.155776E+01    50.0936    5.298764E+01   -7.209989E+01   1.087497E+02
0      25  -1.025000E-02    -3.578105E+01  -1.065341E+01  -4.672659E+01   -52.5249    2.516897E+01   -7.160343E+01   8.696385E+01
            1.025000E-02     3.578105E+01   1.065341E+01   4.672659E+01    37.4751    7.160343E+01   -2.516897E+01   8.696385E+01
0      26  -1.025000E-02    -3.182966E+01  -4.119619E+00  -5.341889E+01   -52.2701    3.721176E+01   -7.316104E+01   9.726101E+01
            1.025000E-02     3.182966E+01   4.119619E+00   5.341889E+01    37.7299    7.316104E+01   -3.721176E+01   9.726101E+01
0      27  -1.025000E-02     2.299595E+01   2.805371E+00  -2.599127E+01   -34.3866    4.078365E+01   -1.498233E+01   4.998811E+01
            1.025000E-02    -2.299595E+01  -2.805371E+00   2.599127E+01    55.6134    1.498233E+01   -4.078365E+01   4.998811E+01
0      28  -1.025000E-02     3.081320E+01   1.095112E+01   2.078276E+00     5.9099    3.102833E+01    1.073599E+01   2.729284E+01
            1.025000E-02    -3.081320E+01  -1.095112E+01  -2.078276E+00   -84.0901   -1.073599E+01   -3.102833E+01   2.729284E+01
```

Use of AEPARM in Nonlinear Solutions

The Static Aeroelastic Analysis write-up in Chapter 3: Aeroelastic Modeling talks about the use of user-defined AEPARM entries in triggering TRIM solutions based on multiple values of the same extra point variable. The section dealing with Interconnection of Structure with Aerodynamics (Chapter 2: Aeroelastic Analysis with MSC Nastran) talks about the care that needs to be due to the use of multi-variate interpolation used in SPLINE functions. This example shows a simple implementation of this concept to show the use of varying engine forces introduced by a thruster at different gimbal angles.

We make use of the HA144F example provided in Listing 7-22 of the FSW Airplane with Bodies example from earlier in the chapter as a starting point. Most of the input is the same as that provided therein. Both the rigid and flexible loads are calculated and used in this case. The changes to be noticed are the introduction of two AEPARMs as aerodynamic control points, the use of UXVEC to quantify these user-specified control points, and the application of specific AEFORCEs on the left and right pylon nodes of the structural grid. It should also be seen that all 6 DOFs are SUPORTed at grid point 90, where specific drag forces are identified. The updated input deck is named osprey.dat as shown in Listing 7-31.

Listing 7-31 Listing 7-31 Input File for Use of AEPARM in Example OSPREY.DAT

```
ID MSC, osprey.dat $ Based on HA144F.dat
$$$$$$    USERS GUIDE FOR AEROELASTIC ANALYSIS EXAMPLE HA144F     $$$$$$
$                                                                     $
$       MODEL DESCRIPTION        FULL SPAN 30 DEG FWD SWEPT WING      $
$                                WITH AILERON, CANARD AND AFT SWEPT   $
$                                VERTICAL FIN AND RUDDER.             $
$                                BAR MODEL WITH DUMBBELL MASSES.      $
$                                INCLUDES NONLINEAR PARAMETRIC STATIC $
$                                APPLIED LOADS BASED ON ENGINE AND    $
$                                GIMBAL ANGLE CONTROLLERS.            $
$                                                                     $
$       SOLUTION                 QUASI-STEADY AEROELASTIC ANALYSIS    $
$                                USING DOUBLET-LATTICE METHOD         $
$                                AERODYNAMICS AT MACH NO. 0.9.        $
$                                                                     $
$       OUTPUT                   PLOTS OF THE STICK MODEL AND AERO    $
$                                GRID, LISTS OF RESTRAINED AND        $
$                                UNRESTRAINED SYMMETRIC AND ANTI-     $
$                                SYMMETRIC STABILITY DERIVATIVES,     $
$                                AERODYNAMIC FORCES AND PRESSURES     $
$                                PLUS STRESSES AND DEFLECTIONS FOR    $
$                                LEVEL FLIGHT AND SEVERAL UNSYM-      $
$                                METRICAL MANUEVERS.                  $
$                                                                     $
$                                                                     $
$$$$$$$$                                                       $$$$$$$$
TIME 10 $ CPU TIME IN MINUTES
DIAG 8,15,19
SOL 144 $ STATIC AERO
CEND

TITLE = EXAMPLE HA144F: FSW WITH FUSELAGE, 3 CONTROLS & 2 STOR HA144F
SUBTI = UNSYMMETRIC FLIGHT CONDITIONS, DOUBLET-LATTICE AERO
LABEL = FULL-SPAN MODEL WITH DISPLACED CANARD
  ECHO    = sort
  SPC     = 1    $ SYMMETRIC CONSTRAINTS
  MPC     = 10   $ CANARD/FUSELAGE STRUCTURAL CONNECTIONS
  FORCE   = ALL  $ PRINT ALL FORCES
  GPFORCE = ALL
  TRIMF(applied,air,inertia) = all
  OLOAD   = ALL
  AEROF   = ALL  $ PRINT ALL AERODYNAMIC FORCES
SUBCASE 1
  TRIM = 1       $ HIGH SPEED LEVEL FLIGHT
BEGIN BULK
```

```
$*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
$                                                                        $
$        THE ANNOTATIONS IN THIS INPUT DECK ARE INTENDED TO              $
$        EXPLAIN THE DATA ON THE CARD IMAGES FOR THIS SPECIFIC           $
$        EXAMPLE WITHOUT REFERENCE TO THE VARIOUS MANUALS WHERE          $
$        MORE GENERAL DESCRIPTIONS WILL BE FOUND.                        $
$                                                                        $
$*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
$                                                                        $
$                       * * * STRUCTURAL DATA * * *                      $
$                                                                        $
$                            (LB-FT-SEC SYSTEM)                          $
$                                                                        $
$                          * * GRID GEOMETRY * *                         $
$                                                                        $
$        GRID  90 - 100 (T3) FUSELAGE POINTS                             $
$        GRID 110 - 122 (T3) WING POINTS                                 $
$        GRID 310 - 312 (t3) FIN POINTS                                  $
$                                                                        $
$                            * FUSELAGE GRID *                           $
$                                                                        $
$        THE GRID ENTRY DEFINES THE LOCATION OF A STRUCTURAL GRID        $
$        POINT.  LISTED ARE ITS COORDINATE SYSTEM ID, ITS LOCATION,      $
$        THE ID OF THE COORDINATE SYSTEM IN WHICH ITS DISPLACEMENTS      $
$        ARE DEFINED, ITS PERMANENT SINGLE-POINT CONSTRAINTS AND         $
$        ITS ASSOCIATED SUPERELEMENT ID.                                 $
$                                                                        $
$       ID      CP      X1      X2      X3      CD      PS      SEID
GRID    1000    100     0.0     0.0     0.0     100     123456
PARAM   GRDPNT  1000

$
GRID    90              15.     0.      0.
GRID    97              0.      0.      0.
GRID    98              10.     0.      0.
GRID    99              20.     0.      0.
GRID    100             30.     0.      0.
GRID    890             15.     -2.0    0.
GRID    910             15.     +2.0    0.
$                                                                        $
$                       * LEFT CANARD GRID *
$       ID      CP      X1      X2      X3      CD      PS      SEID
GRID    88      900     5.0     -5.0    0.0
GRID    881     900     2.5     -5.0    0.0
GRID    882     900     7.5     -5.0    0.0
GRID    89      900     5.0     -2.0    0.0
GRID    891     900     2.5     -2.0    0.0
GRID    892     900     7.5     -2.0    0.0
$
RBAR    881     88      881     123456
RBAR    882     88      882     123456
RBAR    891     89      891     123456
RBAR    892     89      892     123456
$
$                       * RIGHT CANARD GRID *
$
GRID    91      900     5.0     2.0     0.0
GRID    911     900     2.5     2.0     0.0
GRID    912     900     7.5     2.0     0.0
GRID    92      900     5.0     5.0     0.0
GRID    921     900     2.5     5.0     0.0
GRID    922     900     7.5     5.0     0.0
$
RBAR    911     91      911     123456
RBAR    912     91      912     123456
RBAR    921     92      921     123456
RBAR    922     92      922     123456
$
```

```
$                  ** CANARD COORDINATE SYSTEMS **
$
$                   * CANARD HINGELINE AND ELASTIC AXIS *
$
$       CID     CS      A1      A2      A3      B1      B2      B3      +CRD
CORD2R  90      900     5.0     0.0     0.0     5.0     0.0     15.0    +CRD90C
$       C1      C2      C3
+CRD90C 20.0    0.0     0.0
$
$           * COORDINATES AT CANARD/INTERFERENCE TUBE INTERSECTION *
$
$       CID     CS      A1      A2      A3      B1      B2      B3      +CRD
CORD2R  900             10.0    0.0     1.5     10.0    0.0     15.0    +CRD900C
$       C1      C2      C3
+CRD900C20.0    0.0     1.5
$
$                         * RIGHT WING GRID *                           $
$                                                                       $
$       ID      CP      X1      X2      X3      CD      PS      SEID
GRID    111             24.61325 +5.    0.
GRID    110             27.11325 +5.    0.
GRID    112             29.61325 +5.    0.
GRID    115             24.22650+10.    0.
GRID    121             18.83975+15.    1.
GRID    120             21.33975+15.    1.
GRID    122             23.83975+15.    1.
$                                                                       $
$                         * RIGHT STORE GRID *
$
GRID    150             19.22650+10.    -1.5
GRID    151             24.22650+10.    -1.5
$
$                         * LEFT WING GRID *                            $
$                                                                       $
$       ID      CP      X1      X2      X3      CD      PS      SEID
GRID    211             24.61325 -5.    0.
GRID    210             27.11325 -5.    0.
GRID    212             29.61325 -5.    0.
GRID    215             24.22650-10.    0.
GRID    221             18.83975-15.    1.
GRID    220             21.33975-15.    1.
GRID    222             23.83975-15.    1.
$                                                                       $
$                         * LEFT STORE GRID *
$
GRID    250             19.22650-10.    -1.5
GRID    251             24.22650-10.    -1.5
$
$                             * FIN GRID *                              $
$                                                                       $
GRID    310             32.88675+0.     5.
GRID    311             30.38675+0.     5.
GRID    312             35.38675+0.     5.
$                                                                       $
$                 * * STRUCTURAL STIFFNESS PROPERTIES * *               $
$                                                                       $
$                        * FUSELAGE STRUCTURE *                         $
$                                                                       $
$        THE CBAR ENTRY DEFINES A SIMPLE BEAM ELEMENT.  LISTED ARE      $
$        ITS PROPERTY ENTRY ID, THE TWO GRID POINTS JOINED BY THE       $
$        BEAM AND COMPONENTS OF A VECTOR FROM THE FIRST POINT.          $
$        THIS VECTOR DEFINES THE DIRECTION OF THE STRUCTURAL DE-        $
$        FLECTION OF THE POINT AND ITS POSITIVE SENSE.                  $
$                                                                       $
$       EID     PID     GA      GB      X1,GO   X2      X3
CBAR    101     100     97      98      0.      0.      1.
CBAR    102     100     98      90      0.      0.      1.
CBAR    104     100     90      99      0.      0.      1.
CBAR    103     100     99      100     0.      0.      1.
$
```

```
$        THE PBAR ENTRY DEFINES GEOMETRIC PROPERTIES OF THE BEAM.       $
$        LISTED ARE ITS ASSOCIATED MATERIAL ENTRY ID, ITS CROSS SEC-    $
$        TIONAL AREA, AREA MOMENTS OF INERTIA, TORSIONAL MOMENT         $
$        OF INERTIA AND NON-STRUCTURAL MASS PER UNIT AREA.  THE         $
$        OPTIONAL CONTINUATION ENTRY CONTAINS STRESS RECOVERY           $
$        COEFFICIENTS, I.E., Y,Z COORDINATES WHERE STRESSES ARE         $
$        TO BE COMPUTED.  K1 AND K2 ARE AREA FACTORS FOR SHEAR          $
$        STIFFNESS (DEFAULT IS BLANK; THEN SHEAR STIFFNESS IS           $
$        INFINITE, I.E., SHEAR FLEXIBILITY IS ZERO.  I12 IS THE         $
$        AREA PRODUCT OF INERTIA.                                       $
$                                                                       $
$       PID     MID     A       I1      I2      J       NSM
PBAR    100     1       4.0     .347222 .30     1.0                     +PB1F
$       C1      C2      D1      D2      E1      E2      F1      F2
+PB1F   1.0     1.0     1.0     -1.0    -1.0    1.0     -1.0    -1.0    +PB2F
$       K1      K2      I12
+PB2F                   0.0
$                                                                       $
$                         * CANARD STRUCTURE *
$       EID     PID     GA      GB      X1,G0   X2      X3
CBAR    89      101     88      89      0.      0.      1.
CBAR    90      101     890     90      0.      0.      1.
CBAR    91      101     90      910     0.      0.      1.
CBAR    92      101     91      92      0.      0.      1.
$
$             * LEFT CANARD/FUSELAGE STRUCTURAL CONNECTION *
$
MPC     10      89      1       1.0     890     1       -1.0
MPC     10      89      2       1.0     890     2       -1.0
MPC     10      89      3       1.0     890     3       -1.0
MPC     10      89      4       1.0     890     4       -1.0
MPC     10      89      5       1.0     890     5       -1.0
MPC     10      89      6       1.0     890     6       -1.0
$
$             * RIGHT CANARD/FUSELAGE STRUCTURAL CONNECTION *
$
MPC     10      91      1       1.0     910     1       -1.0
MPC     10      91      2       1.0     910     2       -1.0
MPC     10      91      3       1.0     910     3       -1.0
MPC     10      91      4       1.0     910     4       -1.0
MPC     10      91      5       1.0     910     5       -1.0
MPC     10      91      6       1.0     910     6       -1.0
$
$                        * RIGHT WING STRUCTURE *                       $
$                                                                       $
$       EID     PID     GA      GB      X1,GO   X2      X3
CBAR    110     101     100     110     0.      0.      1.
CBAR    115     101     110     115     0.      0.      1.
CBAR    120     101     115     120     0.      0.      1.
$                                                                       $
$        THE RBAR ENTRY DEFINES A RIGID BAR.  LISTED ARE THE GRID       $
$        POINTS AT EACH END AND THE DEPENDENT AND INDEPENDENT DOFS      $
$        AT EACH END.  THE NUMBER OF INDEPENDENT DOFS AT THE TWO        $
$        ENDS MUST EQUAL SIX.  BY DEFAULT THOSE NOT DECLARED INDE-      $
$        PENDENT ARE MADE DEPENDENT.                                    $
$                                                                       $
$       EID     GA      GB      CNA     CNB     CMA     CMB
RBAR    111     110     111     123456
RBAR    112     110     112     123456
RBAR    121     120     121     123456
RBAR    122     120     122     123456
$                                                                       $
$       PID     MID     A       I1      I2      J       NSM
PBAR    101     1       1.5     0.173611+2.0    0.462963                +PB1W
$       C1      C2      D1      D2      E1      E2      F1      F2
+PB1W   0.5     3.0     0.5     -3.0    -0.5    3.0     -0.5    -3.0    +PB2W
$       K1      K2      I12
+PB2W                   0.0
```

```
$                                                                              $
$                    * LEFT WING STRUCTURE *                                   $
$                                                                              $
$       EID     PID     GA      GB      X1,GO   X2      X3
CBAR    210     101     100     210     0.      0.      1.
CBAR    215     101     210     215     0.      0.      1.
CBAR    220     101     215     220     0.      0.      1.
$
RBAR    211     210     211     123456
RBAR    212     210     212     123456
RBAR    221     220     221     123456
RBAR    222     220     222     123456
$                                                                              $
$                * RIGHT  PYLON/STORE STRUCTURE *                               $
$                                                                              $
$       EID     PID     GA      GB      X1,GO   X2      X3
CBAR    150     101     150     151     0.      0.      1.
CBAR    151     101     151     115     1.      0.      0.
$
$                * LEFT PYLON/STORE STRUCTURE *                                $
$                                                                              $
$       EID     PID     GA      GB      X1,GO   X2      X3
CBAR    250     101     250     251     0.      0.      1.
CBAR    251     101     251     215     1.      0.      0.
$
$                        * FIN STRUCTURE *                                     $
$                                                                              $
CBAR    310     101     100     310     0.      0.      1.
$                                                                              $
RBAR    311     310     311     123456
RBAR    312     310     312     123456
$                                                                              $
$        THE MAT1 ENTRY DEFINES THE MATERIAL PROPERTIES.  LISTED               $
$        ARE ITS ID, ITS ELASTIC MODULUS, SHEAR MODULUS, POISSONS              $
$        RATIO, MASS DENSITY, TEMPERATURE EXPANSION COEFFICIENT,               $
$        REFERENCE TEMPERATURE AND A STRUCTURAL DAMPING COEFFICIENT.           $
$                                                                              $
$       MID     E       G       NU      RHO     A       TREF    GE
MAT1    1       1.44+9  5.40+8
$                                                                              $
$              * * MASS AND INERTIA PROPERTIES * *                             $
$                                                                              $
$                       * FUSELAGE MASSES *                                    $
$                                                                              $
$        THE CONM2 ENTRY DEFINES A CONCENTRATED MASS.  LISTED ARE              $
$        ITS ID, GRID LOCATION, COORDINATE SYSTEM TO LOCATE THE                $
$        CENTER OF GRAVITY, THE MASS VALUE AND THE LOCATION OF                 $
$        THE CENTER OF GRAVITY RELATIVE TO THE GRID LOCATION.                  $
$                                                                              $
$       EID     G       CID     M       X1      X2      X3
CONM2   97      97      0       3000.0
CONM2   98      98      0       3000.0
CONM2   99      99      0       3000.0
CONM2   100     100     0       3000.0
$                                                                              $
$                      * RIGHT WING MASSES *                                   $
$                                                                              $
CONM2   111     111     0       600.0
CONM2   112     112     0       400.0
CONM2   121     121     0       600.0
CONM2   122     122     0       400.0
$                                                                              $
$                      * LEFT WING MASSES *                                    $
$                                                                              $
CONM2   211     211     0       600.0
CONM2   212     212     0       400.0
CONM2   221     221     0       600.0
CONM2   222     222     0       400.0
$                                                                              $
$                         * FIN MASSES *                                       $
$                                                                              $
CONM2   311     311     0       60.0
CONM2   312     312     0       40.0
```

```
$                                                                       $
$                            * LEFT ELEV MASSES *                       $
$                                                                       $
CONM2   8810    881     0       20.0
CONM2   8820    882     0       40.0
CONM2   8910    891     0       20.0
CONM2   8920    892     0       40.0
$                                                                       $
$                            * RIGHT ELEV MASSES *                      $
$                                                                       $
CONM2   9110    911     0       20.0
CONM2   9120    912     0       40.0
CONM2   9210    921     0       20.0
CONM2   9220    922     0       40.0
$                                                                       $
$                    * * STRUCTURAL PARAMETERS * *                      $
$                                                                       $
$        THE PARAM,WTMASS,GINV CAUSES ALL THE STRUCTURAL MASSES AND     $
$        MASS DENSITIES TO BE MULTIPLIED BY GINV (I.E., BY ONE OVER     $
$        THE ACCELERATION OF GRAVITY).  THE DYNAMIC PRESSURE SUPPLIED   $
$        FOR AERODYNAMIC FORCE CALCULATIONS WILL NOT BE MULTIPLIED      $
$        BY GINV.                                                       $
$                                                                       $
PARAM   WTMASS  .031081
PARAM   AUNITS  .031081
$                                                                       $
$        THE SUPORT ENTRY IDENTIFIES A GRID POINT OR A SCALAR POINT     $
$        AND SPECIFIES THE DOF COMPONENTS IN WHICH THE USER DESIRES     $
$        REACTIONS TO BE APPLIED TO PREVENT RIGID BODY MOTION.  IT      $
$        THUS INVOKES THE SOLUTION OF THE BALANCE EQUATIONS TO DETER-   $
$        MINE THE REACTIONS.  IN THE STATIC AEROELASTIC SOLUTION        $
$        THE DOF COMPONENTS MUST BE CONSISTENT WITH THE UNDEFINED       $
$        VARIABLES ON THE TRIM ENTRIES.                                 $
$                                                                       $
$       ID      C
SUPORT  90      123456
$                                                                       $
$                      * * * AERODYNAMIC DATA * * *                     $
$                                                                       $
$                           (LB-FT-SEC SYSTEM)                          $
$                                                                       $
$                        * * ELEMENT GEOMETRY * *                       $
$                                                                       $
$        THE AEROS ENTRY IS UNIQUE TO THE STATIC AEROELASTICITY         $
$        SOLUTION, SOL21.  ACSID IDENTIFIES THE AERO COORDINATE         $
$        SYSTEM, RCSID IDENTIFIES THE REFERENCE COORDINATE SYS-         $
$        TEM FOR RIGID BODY MOTION.  REFC IS THE REFERENCE CHORD.       $
$        REFB IS THE REFERENCE SPAN.  REFS IS THE REFERENCE WING        $
$        AREA.  SYMXZ AND SYMXY ARE SYMMETRY KEYS.                      $
$                                                                       $
$       ACSID   RCSID   REFC    REFB    REFS    SYMXZ   SYMXY
AEROS   1       100     10.0    40.0    400.0
$                                                                       $
$        THIS CORD2R ENTRY DEFINES THE AERO COORDINATE SYSTEM           $
$        FLAGGED BY THE AEROS ENTRY.  THE ORIGIN IS AT THE CANARD       $
$        QUARTER CHORD.  LISTED ARE THE ORIGIN, A POINT ALONG THE       $
$        Z AXIS AND A POINT IN THE X-Z PLANE, ALL IN THE RID            $
$        COORDINATE SYSTEM.                                             $
$                                                                       $
$       CID     RID     A1      A2      A3      B1      B2      B3
CORD2R  1       0       12.5    0.      0.      12.5    0.      10.     +CRD1
$       C1      C2      C3
+CRD1   20.     0.      0.
$                                                                       $
$        THIS CORD2R ENTRY DEFINES THE NACA COORDINATE SYSTEM TO        $
$        WHICH ALL THE STABILITY DERIVATIVES AND TRIM CONDITIONS        $
$        WILL BE REFERENCED.                                            $
$                                                                       $
$       CID     RID     A1      A2      A3      B1      B2      B3
CORD2R  100     0       15.0    0.0     0.0     15.0    0.0     -10.0   +CRD100
$       C1      C2      C3
+CRD100 0.0     0.0     0.0
```

```
$                                                                       $
$                                                                       $
$                      * WING AERODYNAMIC MODEL *                       $
$                                                                       $
$        THE CAERO1 ENTRY IS USED FOR DOUBLET-LATTICE AERODYNAMICS.     $
$        LISTED ARE ITS PAERO ENTRY ID AND THE COORDINATE SYSTEM        $
$        FOR LOCATING THE INBOARD AND OUTBOARD LEADING EDGE POINTS      $
$        (1 AND 4).  NSPAN AND NCHORD, OR LSPAN AND LCHORD, ARE         $
$        USED TO PARTITION THE WING INTO AERODYNAMIC PANELS,            $
$        THE FORMER FOR UNIFORMLY SPACED PANELS AND THE LATTER          $
$        FOR NON-UNIFORMLY SPACED PANELS.  IGID IS THE ID OF ITS        $
$        ASSOCIATED INTERFERENCE GROUP.  THE CONTINUATION ENTRY         $
$        DEFINES POINTS 1 AND 4, THE ROOT CHORD AND TIP CHORD.          $
$        THE BOXES FORMED BY THE GRID LINES WILL BE NUMBERED            $
$        BEGINNING WITH EID SO CHOOSE A NUMBER THAT IS UNIQUE,          $
$        AND IS GREATER THAN ALL STRUCTURAL GRID, SCALAR AND            $
$        EXTRA POINT IDS.                                               $
$                                                                       $
$                     * RIGHT INBOARD WING *
$       EID     PID     CP      NSPAN   NCHORD  LSPAN   LCHORD  IGID
CAERO1  21104   1000            3       4                       1       +CARW2
$      ( FWD LEFT POINT  )     CHORD  ( FWD RIGHT POINT   )     CHORD
$       X1      Y1      Z1      X12     X4      Y4      Z4      X14
+CARW2  23.55662+2.5     0.      10.     19.22650+10.    0.      10.
$                                                                       $
$                     * RIGHT OUTBOARD WING *
$       EID     PID     CP      NSPAN   NCHORD  LSPAN   LCHORD  IGID
CAERO1  31116   1000            4       4                       1       +CARW3
$      ( FWD LEFT POINT  )     CHORD  ( FWD RIGHT POINT   )     CHORD
$       X1      Y1      Z1      X12     X4      Y4      Z4      X14
+CARW3  19.22650+10.    0.      10.     13.45299+20.    2.      10.
$                                                                       $
$                                                                       $
$                           * LEFT OUTBOARD WING *
CAERO1  42100   1000            4       4                       1       +CALW1
+CALW1  13.45299-20.    2.      10.     19.22650-10.    0.      10.
$                                                                       $
$                           * LEFT INBOARD WING *
CAERO1  52116   1000            3       4                       1       +CALW2
+CALW2  19.22650-10.    0.      10.     23.55662-2.5    0.      10.
$                                                                       $
$
$                        * CANARD AERODYNAMIC MODEL *                   $
$                                                                       $
$                          * RIGHT OUTBOARD SIDE *
CAERO1  11000   1000    900             4       1000            1       +CARC2
+CARC2  0.0     2.0     0.0     10.0    0.0     5.0     0.0     10.
$                                                                       $
AEFACT  1000    0.0     0.16667 1.0
$
$                          * LEFT OUTBOARD SIDE *
CAERO1  32000   1000    900             4       2000            1       +CALC1
+CALC1  0.0     -5.0    0.0     10.     0.0     -2.0    0.0     10.
$                                                                       $
AEFACT  2000    0.0     0.83333 1.0
$
$                                                                       $
$                       * FIN AERODYNAMIC MODEL *                       $
$                                                                       $
CAERO1  53100   1000            3       4                       1       +CA1FI1
+CA1FI1 30.7735 0.      10.     10.     26.44334 0.0    2.5     10.
$                                                                       $
$
$
$                       * FUSELAGE AERODYNAMIC MODEL *
$
$       PID     B1      B2      B3      B4      B5      B6
PAERO1  1000    54000   54510   64610
$
$       EID     PID     CP      NSB     NINT    LSB     LINT    IGID    +CA2
CAERO2  54000   4020            8       8                       1       +CA2F
$       X1      Y1      Z1      X12
+CA2F   -5.0    0.0     0.0     40.0
$
```

```
$       PID     ORIENT  WIDTH   AR      LRSB    LRIB    LTH1    LTH2    +PA2
PAERO2  4020    ZY      2.5     1.0     4015            4018            +PA2F
$       THI1    THN1    THI2    THN2
+PA2F   1       8
$
$                     * (LRSB) SLENDER BODY HALF-WIDTHS *
$
AEFACT  4015    0.0     1.111   1.778   2.0     2.0     2.0     2.5     +LRSBF
+LRSBF  2.5     2.5
$
$                       * (LTH1 & 2) THETA ARRAYS *
$
AEFACT  4018    45.     135.    225.    315.
$
$
$                       * RIGHT PYLON/STORE AERODYNAMIC MODEL *
$
$                            * RIGHT PYLON *
CAERO1  53500   1000            1       2                       1       +CA1RP
+CA1RP  21.72650+10.0   0.      5.0     21.72650+10.0   -1.0    5.0
$                                                                       $
$                            * RIGHT STORE *
$
$       EID     PID     CP      NSB     NINT    LSB     LINT    IGID    +CA2
CAERO2  54510   4520            4       4                       1       +CA2RS
$       X1      Y1      Z1      X12
+CA2RS  19.22650+10.0   -1.5    10.0
$                                                                       $
$       PID     ORIENT  WIDTH   AR      LRSB    LRIB    LTH1    LTH2    +PA2
PAERO2  4520    ZY      0.5     1.0     4515            4018            +PA2RS
$       THI1    THN1    THI2    THN2
+PA2RS  1       4
$
$                     * (LRSB) SLENDER BODY HALF-WIDTHS *
$
AEFACT  4515    0.0     0.5     0.5     0.5     0.0
$
$
$                       * LEFT PYLON/STORE AERODYNAMIC MODEL *
$
$                            * LEFT PYLON *
CAERO1  53600   1000            1       2                       1       +CA1LP
+CA1LP  21.72650-10.0   0.      5.0     21.72650-10.0   -1.0    5.0
$                                                                       $
$                            * LEFT STORE *
$
$       EID     PID     CP      NSB     NINT    LSB     LINT    IGID    +CA2
CAERO2  64610   4520            4       4                       1       +CA2LS
$       X1      Y1      Z1      X12
+CA2LS  19.22650-10.0   -1.5    10.0
$                                                                       $
$
$                                                                       $
$                * * SPLINE FIT ON THE LIFTING SURFACES * *             $
$                                                                       $
$                     * BEAM SPLINE FIT ON THE WING *                   $
$                                                                       $
$        THE SPLINE2 ENTRY SPECIFIES A BEAM SPLINE FOR INTERPOLAT-      $
$        ION OVER THE REGION OF THE CAERO ENTRY (ID1 AND ID2 ARE        $
$        THE FIRST AND LAST BOXES IN THIS REGION).  SETG REFERS         $
$        TO A SET1 ENTRY WHERE THE STRUCTURAL GRID POINTS ARE           $
$        DEFINED.  DZ AND DTOR ARE SMOOTHING CONSTANTS FOR LINEAR       $
$        ATTACHMENT AND TORSIONAL FLEXIBILITIES.  CID IDENTIFIES        $
$        THE CORD2R ENTRY THAT DEFINES THE SPLINE AXIS.  DTHX AND       $
$        DTHY ARE ROTATIONAL ATTACHMENT FLEXIBILITIES (-1. SPECIFIES    $
$        NO ATTACHMENT).                                                $
$                                                                       $
$                          * RIGHT INBOARD WING *                       $
$       EID     CAERO   ID1     ID2     SETG    DZ      DTOR    CID
SPLINE2 1602    21104   21104   21115   1101    0.      1.      2       +SPRW2
$       DTHX    DTHY
+SPRW2  -1.     -1.
$
```

```
$                           * RIGHT OUTBOARD WING *                        $
$       EID     CAERO   ID1     ID2     SETG    DZ      DTOR    CID
SPLINE2 1603    31116   31116   31131   1102    0.      1.      3       +SPRW3
$       DTHX    DTHY
+SPRW3  -1.     -1.
$                                                                          $
$        THE SET1 ENTRY DEFINES THE SETS OF STRUCTURAL GRID POINTS         $
$        TO BE USED BY THE BEAM SPLINE FOR INTERPOLATION.                  $
$                                                                          $
$       SID     G1      G2      G3      G4
SET1    1101    100     111     112     115
SET1    1102    115     121     122
$                                                                          $
$                           * LEFT OUTBOARD WING *                         $
$       EID     CAERO   ID1     ID2     SETG    DZ      DTOR    CID
SPLINE2 2601    42100   42100   42115   2102    0.      1.      30      +SPLW1
$       DTHX    DTHY
+SPLW1  -1.     -1.
$                                                                          $
$                           * LEFT INBOARD WING *                          $
$       EID     CAERO   ID1     ID2     SETG    DZ      DTOR    CID
SPLINE2 2602    52116   52116   52127   2101    0.      1.      20      +SPLW2
$       DTHX    DTHY
+SPLW2  -1.     -1.
$                                                                          $
$                                                                          $
$        THE SET1 ENTRY DEFINES THE SETS OF STRUCTURAL GRID POINTS         $
$        TO BE USED BY THE BEAM SPLINE FOR INTERPOLATION.                  $
$                                                                          $
$       SID     G1      G2      G3      G4
SET1    2101    100     211     212     215
SET1    2102    215     221     222
$                                                                          $
$
$                  * BEAM SPLINE FIT ON THE CANARD *                       $
$                                                                          $
$                                                                          $
$                       * RIGHT OUTBOARD SIDE *                            $
SPLINE2 1502    11000   11000   11007   1000    0.      1.      90      +SPRC2
+SPRC2  0.0     0.0
$                                                                          $
SET1    1000    88      89      91      92
$                                                                          $
$                       * LEFT OUTBOARD SIDE *                             $
SPLINE2 2501    32000   32000   32007   1000    0.      1.      90      +SPLC1
+SPLC1  0.0     0.0
$                                                                          $
$                    * BEAM SPLINE FIT ON THE FIN *                        $
$                                                                          $
SPLINE2 3100    53100   53100   53111   3100    0.      1.      300     +SP2FI1
+SP2FI1 -1.     -1.
$                                                                          $
SET1    3100    99      100     311     312
$                                                                          $
$                    * BEAM SPLINE FIT ON THE PYLONS *                     $
$                                                                          $
$                           * RIGHT PYLON *
$
SPLINE2 4520    53500   53500   53501   4521    0.      1.      450     +SP2RP
+SP2RP  -1.     -1.
$                                                                          $
SET1    4521    115     150     151
$                                                                          $
$                           * LEFT PYLON *
$
SPLINE2 4620    53600   53600   53601   4621    0.      1.      460     +SP2LP
+SP2LP  -1.     -1.
$                                                                          $
SET1    4621    215     250     251
$                                                                          $
$
```

```
$                     * BEAM SPLINE FIT ON THE BODIES *                  $
$                                                                        $
$                            * FUSELAGE *
$
SPLINE2 4000    54000   54000   54007   4001    0.      1.              +SP2F
+SP2F           -1.
$                                                                        $
SET1    4001    97      98      99      100
$                                                                        $
$                                                                        $
$                            * RIGHT STORE *
$
SPLINE2 4525    54510   54510   54513   4525    0.      1.              +SP2RS
+SP2RS          -1.
$                                                                        $
SET1    4525    150     151
$                                                                        $
$                                                                        $
$                            * LEFT STORE *
$
SPLINE2 4625    64610   64610   64613   4625    0.      1.              +SP2LS
+SP2LS          -1.
$                                                                        $
SET1    4625    250     251
$                                                                        $
$        THE CORD2R ENTRY DEFINES THE COORDINATE SYSTEM IN WHICH THE     $
$        BEAM SPLINE EXTENDS ALONG THE WING Y-AXIS.  IT LISTS THE        $
$        ORIGIN, A POINT ALONG THE Z-AXIS AND A POINT IN THE X-Z         $
$        PLANE.                                                          $
$                                                                        $
$                  * INBOARD RIGHT WING SPLINE AXIS *                    $
$                                                                        $
$       CID     CS      A1      A2      A3      B1      B2      B3
CORD2R  2       0       30.     0.      0.      30.     0.      10.     +CRD2RW
$       C1      C2      C3
+CRD2RW 38.66025+5.0    0.
$                                                                        $
$                          * OUTBOARD RIGHT WING SPLINE AXIS *           $
$                                                                        $
$       CID     CS      A1      A2      A3      B1      B2      B3
CORD2R  3       0       24.22650+10.    0.      25.07982 8.293369.853293+CRD2ORW
$       C1      C2      C3
+CRD2ORW34.2265015.77350+0.
$                                                                        $
$                          * INBOARD LEFT WING SPLINE AXIS *            $
$                                                                        $
$       CID     CS      A1      A2      A3      B1      B2      B3
CORD2R  20      0       30.0    0.      0.      30.     0.      10.     +CRD2ILW
$       C1      C2      C3
+CRD2ILW38.66025-5.0    0.
$                                                                        $
$                          * OUTBOARD LEFT WING SPLINE AXIS *            $
$                                                                        $
$       CID     CS      A1      A2      A3      B1      B2      B3
CORD2R  30      0       24.22650-10.    0.      25.07982-8.293369.853293+CRD2OLW
$       C1      C2      C3
+CRD2OLW34.22650-15.7735+0.
$                                                                        $
$                           * FIN SPLINE AXIS *                          $
$                                                                        $
CORD2R  300     0       30.0    0.      0.      30.0    10.0    0.      +CRD2FI
+CRD2FI 20.0    0.0     5.7735
$
$                         * RIGHT PYLON SPLINE AXIS *
$
CORD2R  450     0       24.22650+10.0   0.      24.22650+20.0   0.0     +CRD2RP
+CRD2RP 30.0    20.0    0.0
$
$                         * LEFT PYLON SPLINE AXIS *                     $
$
CORD2R  460     0       24.22650-10.0   0.      24.22650+20.0   0.0     +CRD2LP
+CRD2LP 30.0    20.0    0.0
```

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```
$
$                                                                        $
$                  * CONTROL SURFACE DEFINITION *                        $
$                                                                        $
$        THE AESURF ENTRY DEFINES AN AERODYNAMIC CONTROL SURFACE.        $
$        LISTED ARE THE ALPHANUMERIC NAME OF THE SURFACE, THE ID         $
$        OF A COORDINATE SYSTEM THAT DEFINES THE HINGE LINE AND          $
$        THE ID OF AN AELIST ENTRY.                                      $
$                                                                        $
$       ID      LABEL   CID1    ALID1   CID2    ALID2
AESURF  505     ELEV    90      1000    90      2000
AESURFS 505     ELEV            50501           50502
SET1    50501   911     912     921     922     91      92
SET1    50502   881     882     891     892     88      89
AESURF  518     AILERON 110     1100    210     2100
AESURF  519     RUDDER  301     3000
$                                                                        $
$        THE AELIST ENTRY LISTS AERODYNAMIC BOXES THAT LIE ON THE        $
$        CONTROL SURFACE.                                                $
$                                                                        $
$       SID     E1      E2      E3      ETC
AELIST  1000    11000   THRU    11007
AELIST  2000    32000   THRU    32007
AELIST  1100    31119   31123   31127   31131
AELIST  2100    42103   42107   42111   42115
AELIST  3000    53103   53107   53111
$                                                                        $
$                    * CONTROL SURFACE HINGE LINES *                     $
$                                                                        $
$                            * CANARD *                                  $
$        THE COORDINATE SYSTEM, CORD2R,1, REFERENCED BY THE AEROS ENTRY  $
$        IS THE CANARD HINGE LINE, AND NEEDS NO FURTHER DEFINITION       $
$                                                                        $
$                         * RIGHT AILERON *                              $
CORD2R  110     0       26.7265 10.0    0.      26.7265 10.0    -10.0   +CRD2RA
+CRD2RA 36.7265 15.7735 0.
$                                                                        $
$                         * LEFT AILERON *                               $
CORD2R  210     0       26.7265 -10.0   0.      26.7265 -10.0   10.0    +CRD2LA
+CRD2LA 36.7265 -15.7735 0.
$                                                                        $
$                             * RUDDER *                                 $
CORD2R  301     0       32.5    0.      0.      32.5    -10.    0.0     +CRD2R
+CRD2R  22.5    0.      5.7735
$                                                                        $
$                   * * USER SUPPLIED INPUT DATA * *                     $
$                                                                        $
$        THE DMI ENTRY ACCOMMODATES DIRECT INPUT OF USER SUPPLIED        $
$        MATRICES OF DATA.  LISTED ARE THE NAME OF THE MATRIX, THE       $
$        FORM OF MATRIX (IN THIS CASE DIAGONAL), THE TYPE OF DATA        $
$        (IN THIS CASE REAL SINGLE PRECISION), BEING INPUT AND THE       $
$        TYPE EXPECTED AT OUTPUT (IN THIS CASE TO BE DETERMINED          $
$        INTERNALLY).  M IS THE NUMBER OF ROWS AND N IS THE NUMBER       $
$        OF COLUMNS.  THE DATA IS EXPECTED BY COLUMNS.  THE CONTIN-      $
$        UATION ENTRY LISTS THE COLUMN NO., THE ROW NO. OF THE FIRST     $
$        NON-ZERO ELEMENT AND THE FOLLOWING ELEMENTS IN THAT COLUMN.     $
$                                                                        $
$     * INITIAL DOWNWASHES (E.G., DUE TO INCIDENCE,TWIST OR CAMBER) *    $
$                                                                        $
$
$                                                                        $
$                  * * * SOLUTION SPECIFICATIONS * * *                   $
$                                                                        $
$                       * * AERODYNAMIC DOFS * *                         $
$                                                                        $
$        THE AESTAT ENTRY LISTS TRIM VARIABLES USED TO SPECIFY           $
$        RIGID BODY MOTIONS.  THESE AND THE CONTROL SURFACE              $
$        ROTATIONS MAKE UP THE VARIABLES IN THE EQUATIONS OF             $
$        MOTION.                                                         $
$                                                                        $
```

```
$       ID      LABEL
AESTAT  501     ANGLEA
AESTAT  503     URDD3
AESTAT  511     SIDES
AESTAT  512     YAW
AESTAT  513     ROLL
AESTAT  517     URDD1
$
$ Engine assembly (Gimbal angle is +up and zero aligned with flight)
AEPARM  601     ENG_F
AEPARM  611     GIMBAL
AEFORCE 0.9     ASYMM   ASYMM   6011    STRUCT  6011
AEFORCE 0.9     ASYMM   ASYMM   6015    STRUCT  6015
AEFORCE 0.9     ASYMM   ASYMM   6019    STRUCT  6019
$
$ perform a gimbal sweep over 1, 2, and 3 degs
$-------$-------$-------$-------$-------$-------$-------$-------
UXVEC   6011
        ENG_F   1.0     GIMBAL  1.0
FORCE   6011    150             2500.   0.0     -1.0    0.0
FORCE   6011    250             2500.   0.0     -1.0    0.0
UXVEC   6015
        ENG_F   1.0     GIMBAL  2.0
FORCE   6015    150             2500.   -1.0    0.0     0.0
FORCE   6015    250             2500.   -1.0    0.0     0.0
UXVEC   6019
        ENG_F   1.0     GIMBAL  3.0
FORCE   6019    150             2500.   0.0     1.0     0.0
FORCE   6019    250             2500.   0.0     1.0     0.0
$
FORCE   6011    90      0       -5000.  0.0     -1.0    0.0
FORCE   6015    90      0       -5000.  -1.0    0.0     0.0
FORCE   6019    90      0       -5000.  0.0     1.0     0.0
$
$                                                                       $
$                     * * TRIM CONDITIONS * *                           $
$                                                                       $
$        THE TRIM ENTRY SPECIFIES CONSTRAINTS FOR THE TRIM VARIABLES    $
$        LISTED ON THE AESTAT AND AESURF ENTRIES.  LISTED ARE ITS ID,   $
$        THE MACH NUMBER, DYNAMIC PRESSURE AND PAIRS OF TRIM VARI-      $
$        ABLES AND THEIR CONSTRAINED VALUES.  THOSE THAT ARE NOT        $
$        HELD FIXED MUST BE CONSTRAINED BY REACTION FORCES STIPU-       $
$        LATED ON THE SUPORT ENTRY.  SEE SECTION 3.5.3 OF THE THEO-     $
$        RETICAL MANUAL FOR MORE DETAILS.                               $
$                                                                       $
$        TRIM CONDITION 1: LEVEL FLIGHT AT HIGH DYNAMIC PRESSURE        $
$        both engines at full throttle                                  $
$                                                                       $
$-------$-------$-------$-------$-------$-------$-------$-------$-------
TRIM    1       0.9     1200.0  URDD3   -1.0    ENG_F   1.
        GIMBAL  1.      AILERON 0.      RUDDER  0.
$                                                                       $
$                                 * * *                                 $
ENDDATA
```

It should be noted here that the UXVECs listed use two AEPARMs - ENG_F remains constant at 1.0 in all three, while the values vary for only the GIMBAL angle. This is done to make the interpolation matrix generated in the multi-variable spline functions to be non-singular. The TRIM function is called for one of the gimbal angles (= 1.0 deg) listed in the above AEFORCE.

Selected results are shown in Listing 7-32. Of particular interest in this case are the intermediate matrix UXIFV in the output. Rows 9-11 show the weights assigned to the three AEFORCEs provided by the user. Since the gimbal angle specified in the TRIM statement is 1.0, the entire weight is given to the forces listed in the corresponding AEFORCE entry. Absence of the ENG_F control parameter could result in slight variations in the calculated weights due to possible singularities in the interpolation matrices. Listing 7-33 lists the elastic and inertial loads applied on each of the structural grid nodes. It can be seen that the applied AEFORCEs listed for gimbal angle 1.0 in the input deck are applied in the elastic loads.

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Listing 7-32 Selected Output for Use of AEPARM in Example OSPREY.DAT

```
1    EXAMPLE HA144F: FSW WITH FUSELAGE, 3 CONTROLS & 2 STOR HA144F
     UNSYMMETRIC FLIGHT CONDITIONS, DOUBLET-LATTICE AERO
0     FULL-SPAN MODEL WITH DISPLACED CANARD
                                   M O D E L    S U M M A R Y          BULK = 0
                              ENTRY NAME        NUMBER OF ENTRIES
                              ----------        -----------------
                                  AEFACT                        5
                                 AEFORCE                        3
                                  AELIST                        5
                                  AEPARM                        2
                                   AEROS                        1
                                  AESTAT                        6
                                  AESURF                        3
                                 AESURFS                        1
                                  CAERO1                        9
                                  CAERO2                        3
                                    CBAR                       19
                                   CONM2                       22
                                  CORD2R                       14
                                   FORCE                        9
                                    GRID                       41
                                    MAT1                        1
                                     MPC                       12
                                  PAERO1                        1
                                  PAERO2                        2
                                   PARAM                        3
                                    PBAR                        2
                                    RBAR                       18
                                    SET1                       13
                                 SPLINE2                       12
                                  SUPORT                        1
                                    TRIM                        1
                                   UXVEC                        3


N O N - D I M E N S I O N A L   S T A B I L I T Y   A N D   C O N T R O L   D E R I V A T I V E   C O E F F I C I E N T S

                         CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = ASYMMETRIC
                                         MACH = 9.0000E-01                   Q = 1.2000E+03
                         CHORD = 1.0000E+01           SPAN = 4.0000E+01           AREA = 4.0000E+02


                TRANSFORMATION FROM BASIC TO REFERENCE COORDINATES:

               { X }         [ -1.0000   0.0000   0.0000  ]  { X }         { 1.5000E+01 }
               { Y }    =    [  0.0000   1.0000   0.0000  ]  { Y }     +   { 0.0000E+00 }
               { Z }REF      [  0.0000   0.0000  -1.0000  ]  { Z }BAS      { 0.0000E+00 }


                                 CONTROLLER STATE: INTERCEPT ONLY, ALL CONTROLLERS ARE ZERO

TRIM VARIABLE   COEFFICIENT              RIGID                          ELASTIC                             INERTIAL
                                 UNSPLINED        SPLINED       RESTRAINED     UNRESTRAINED     RESTRAINED     UNRESTRAINED

    REF. COEFF.      CX        0.000000E+00   0.000000E+00    0.000000E+00   0.000000E+00    0.000000E+00   2.021095E-29
                     CY       -4.937541E-17  -4.937541E-17   -5.918338E-17  -5.298733E-17    0.000000E+00  -5.298733E-17
                     CZ        3.269485E-16   3.269485E-16    4.288532E-16   5.153352E-16    0.000000E+00   5.153352E-16
                     CMX      -3.510765E-16  -3.505561E-16   -4.242472E-16  -3.684862E-16    0.000000E+00  -3.684838E-16
                     CMY       1.398600E-16   1.393396E-16    2.016895E-16   2.602896E-16    0.000000E+00   2.602874E-16
                     CMZ      -1.305225E-17  -1.158589E-17   -1.783231E-17  -1.264069E-17    0.000000E+00  -1.264069E-17


ANGLEA              CX       0.000000E+00   0.000000E+00    0.000000E+00   0.000000E+00    0.000000E+00  -6.854466E-13
                     CY        8.586539E-13   8.587829E-13    2.455388E-12   5.806143E-13    0.000000E+00   5.885491E-13
                     CZ       -5.040129E+00  -5.040129E+00   -6.537388E+00  -7.982162E+00    0.000000E+00  -7.982162E+00
                     CMX      -5.645173E-13  -5.645681E-13   -8.553110E-13  -1.358747E-12    0.000000E+00  -1.421914E-12
                     CMY      -2.877635E+00  -2.877635E+00   -3.791212E+00  -4.769017E+00    0.000000E+00  -4.768972E+00
                     CMZ       6.306979E-12   6.306968E-12    7.972585E-12   1.129940E-11    0.000000E+00   1.129794E-11

    URDD3            CX        0.000000E+00   0.000000E+00    0.000000E+00   0.000000E+00    2.350556E-17   0.000000E+00
                     CY        0.000000E+00   0.000000E+00   -8.094597E-16   0.000000E+00    8.507724E-17   0.000000E+00
                     CZ        0.000000E+00   0.000000E+00    4.104117E-03   0.000000E+00    3.404167E-02   0.000000E+00
                     CMX       0.000000E+00   0.000000E+00    7.627696E-16   0.000000E+00    4.579783E-16   0.000000E+00
                     CMY       0.000000E+00   0.000000E+00    2.820506E-03   0.000000E+00    7.675974E-03   0.000000E+00
                     CMZ       0.000000E+00   0.000000E+00   -7.793047E-15   0.000000E+00   -2.084352E-17   0.000000E+00

    ELEV             CX        0.000000E+00   0.000000E+00    0.000000E+00   0.000000E+00    0.000000E+00  -6.971447E-15
                     CY        1.354170E-12   1.354170E-12    6.926710E-13   1.225792E-12    0.000000E+00   1.225969E-12
                     CZ       -1.037874E-01  -1.037874E-01   -1.599568E-01  -1.442429E-01    0.000000E+00  -1.442429E-01
                     CMX       4.043416E-13   4.043376E-13    3.767706E-13   4.233636E-13    0.000000E+00   4.234161E-13
                     CMY       2.340462E-01   2.340462E-01    1.988110E-01   2.090414E-01    0.000000E+00   2.090377E-01
                     CMZ      -2.762425E-12  -2.762425E-12   -2.465307E-12  -2.655921E-12    0.000000E+00  -2.655944E-12
```

TRIM VARIABLE	COEFFICIENT	RIGID		ELASTIC		INERTIAL	
		UNSPLINED	SPLINED	RESTRAINED	UNRESTRAINED	RESTRAINED	UNRESTRAINED
SIDES	CX	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	-4.431642E-15
	CY	-7.493702E-01	-7.493702E-01	-7.137761E-01	-7.574412E-01	0.000000E+00	-7.574412E-01
	CZ	-6.791649E-11	-6.791650E-11	-7.624805E-11	-1.011262E-10	0.000000E+00	-1.011158E-10
	CMX	-1.354677E-01	-1.354677E-01	-1.477701E-01	-1.364489E-01	0.000000E+00	-1.366341E-01
	CMY	-4.285448E-11	-4.285446E-11	-4.797877E-11	-6.469035E-11	0.000000E+00	-6.468022E-11
	CMZ	1.900326E-01	1.900326E-01	1.774890E-01	1.929191E-01	0.000000E+00	1.929191E-01
YAW	CX	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	-4.415872E-15
	CY	7.217303E-01	7.217303E-01	6.687397E-01	7.258773E-01	0.000000E+00	7.258773E-01
	CZ	6.157454E-11	6.157451E-11	6.229746E-11	8.659450E-11	0.000000E+00	8.658172E-11
	CMX	9.353674E-02	9.353674E-02	8.854352E-02	8.716076E-02	0.000000E+00	8.733211E-02
	CMY	4.527164E-11	4.527165E-11	4.549560E-11	6.171775E-11	0.000000E+00	6.170548E-11
	CMZ	-2.584813E-01	-2.584813E-01	-2.425676E-01	-2.609158E-01	0.000000E+00	-2.609158E-01
ROLL	CX	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	-3.246751E-14
	CY	-1.516381E-01	-1.516381E-01	-1.633790E-01	-1.589962E-01	0.000000E+00	-1.589962E-01
	CZ	2.506513E-11	2.506551E-11	4.244500E-11	4.216822E-11	0.000000E+00	4.215707E-11
	CMX	-4.362887E-01	-4.362887E-01	-5.353555E-01	-4.656089E-01	0.000000E+00	-4.656302E-01
	CMY	1.625468E-11	1.625482E-11	2.750722E-11	2.752189E-11	0.000000E+00	2.751137E-11
	CMZ	-9.201789E-04	-9.201789E-04	-9.716531E-03	-2.119835E-03	0.000000E+00	-2.119835E-03
URDD1	CX	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	3.404167E-02	0.000000E+00
	CY	0.000000E+00	0.000000E+00	-3.591118E-16	0.000000E+00	-1.812206E-15	0.000000E+00
	CZ	0.000000E+00	0.000000E+00	-6.511015E-04	0.000000E+00	-5.892555E-16	0.000000E+00
	CMX	0.000000E+00	0.000000E+00	-2.329638E-16	0.000000E+00	-1.213360E-18	0.000000E+00
	CMY	0.000000E+00	0.000000E+00	-4.173015E-04	0.000000E+00	-5.583333E-04	0.000000E+00
	CMZ	0.000000E+00	0.000000E+00	1.206123E-15	0.000000E+00	1.498870E-15	0.000000E+00
AILERON	CX	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	1.012939E-14
	CY	4.911805E-02	4.911805E-02	5.241858E-02	4.972159E-02	0.000000E+00	4.972159E-02
	CZ	-2.021516E-11	-2.021501E-11	-2.475612E-11	-2.576436E-11	0.000000E+00	-2.576572E-11
	CMX	2.803041E-01	2.803041E-01	3.064855E-01	2.665156E-01	0.000000E+00	2.665163E-01
	CMY	-1.665452E-11	-1.665455E-11	-1.951101E-11	-2.026875E-11	0.000000E+00	-2.026979E-11
	CMZ	5.166408E-03	5.166408E-03	7.268145E-03	3.014667E-03	0.000000E+00	3.014667E-03
RUDDER	CX	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	-2.829018E-14
	CY	2.297474E-01	2.297474E-01	1.926551E-01	2.194663E-01	0.000000E+00	2.194663E-01
	CZ	4.520822E-12	4.520822E-12	-9.087318E-13	3.558105E-12	0.000000E+00	3.551532E-12
	CMX	3.164924E-02	3.164924E-02	2.404624E-02	2.563858E-02	0.000000E+00	2.568654E-02
	CMY	5.414659E-12	5.414661E-12	1.841631E-12	4.737457E-12	0.000000E+00	4.731508E-12
	CMZ	-1.170619E-01	-1.170619E-01	-1.058725E-01	-1.140374E-01	0.000000E+00	-1.140374E-01

TRIM VARIABLE	COEFFICIENT	RIGID		ELASTIC		INERTIAL	
		UNSPLINED	SPLINED	RESTRAINED	UNRESTRAINED	RESTRAINED	UNRESTRAINED
ENG_F	CX	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	-2.617708E-15
	CY	1.436585E-17	1.436585E-17	-7.244823E-04	-7.696561E-04	0.000000E+00	-7.696561E-04
	CZ	-2.131162E-17	-2.131162E-17	2.206937E-03	2.257438E-03	0.000000E+00	2.257438E-03
	CMX	1.837640E-18	7.812500E-04	5.867058E-04	5.069717E-04	0.000000E+00	5.069988E-04
	CMY	-1.216776E-17	-1.562500E-03	-1.630681E-04	-1.122490E-04	0.000000E+00	-1.122395E-04
	CMZ	-5.268034E-18	2.201302E-03	2.428037E-03	2.448652E-03	0.000000E+00	2.448652E-03
GIMBAL	CX	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	9.330855E-16
	CY	-8.496880E-18	-8.496880E-18	3.622412E-04	3.848280E-04	0.000000E+00	3.848280E-04
	CZ	-5.881425E-17	-5.881425E-17	-2.206937E-03	-2.257438E-03	0.000000E+00	-2.257438E-03
	CMX	-1.070152E-17	-3.906250E-04	-2.933529E-04	-2.534858E-04	0.000000E+00	-2.534994E-04
	CMY	-3.415209E-17	1.562500E-03	1.630681E-04	1.122489E-04	0.000000E+00	1.122395E-04
	CMZ	3.835644E-18	-1.100651E-03	-1.214018E-03	-1.224326E-03	0.000000E+00	-1.224326E-03

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         N O N - D I M E N S I O N A L     H I N G E     M O M E N T     D E R I V A T I V E     C O E F F I C I E N T S

                        CONFIGURATION = AEROSG2D      XY-SYMMETRY = ASYMMETRIC      XZ-SYMMETRY = ASYMMETRIC
                                        MACH = 9.0000E-01                            Q = 1.2000E+03

         CONTROL SURFACE = ELEV          REFERENCE CHORD LENGTH =  1.000000E+00      REFERENCE AREA =  1.000000E+00

             TRIM VARIABLE                RIGID                          ELASTIC                                 INERTIAL
                                                                   RESTRAINED      UNRESTRAINED           RESTRAINED      UNRESTRAINED
             AT REFERENCE          -6.867284E-14               -6.853765E-14   -6.800959E-14          0.000000E+00    1.428061E-15
             ANGLEA                 3.382942E+02                3.349421E+02    3.249956E+02          0.000000E+00   -2.297177E+01
             URDD3                  0.000000E+00                2.488853E-02    0.000000E+00          8.333333E-02    0.000000E+00
             ELEV                   2.997582E+02                3.002177E+02    3.007615E+02          0.000000E+00   -7.391237E-02
             SIDES                  3.372449E-10                3.932819E-10    1.071925E-10          0.000000E+00   -2.957738E-10
             YAW                    1.693685E-10                1.710427E-10    3.750769E-10          0.000000E+00    2.606036E-10
             ROLL                   2.149775E-09                2.693781E-09    2.417121E-09          0.000000E+00    1.245675E-10
             URDD1                  0.000000E+00               -1.959531E-03    0.000000E+00          0.000000E+00    0.000000E+00
             AILERON               -2.017625E-10               -3.466968E-10   -1.815996E-10          0.000000E+00   -8.010614E-11
             RUDDER                 2.728495E-12                6.918771E-12    2.088640E-11          0.000000E+00    1.320746E-11
             ENG_F                  1.430439E-15                6.267454E-03    1.324256E-02          0.000000E+00    4.808124E-03
             GIMBAL                 3.376219E-15               -6.267454E-03   -1.324256E-02          0.000000E+00   -4.808124E-03

         CONTROL SURFACE = AILERON       REFERENCE CHORD LENGTH =  1.000000E+00      REFERENCE AREA =  1.000000E+00

             TRIM VARIABLE                RIGID                          ELASTIC                                 INERTIAL
                                                                   RESTRAINED      UNRESTRAINED           RESTRAINED      UNRESTRAINED
             AT REFERENCE           3.032509E-14                3.261693E-14    3.088116E-14          0.000000E+00    0.000000E+00
             ANGLEA                -1.943512E-10               -2.346319E-10   -2.974900E-10          0.000000E+00    0.000000E+00
             URDD3                  0.000000E+00                1.589215E-13    0.000000E+00          0.000000E+00    0.000000E+00
             ELEV                   5.356271E-12               -7.494005E-13    2.161604E-12          0.000000E+00    0.000000E+00
             SIDES                 -9.736551E-01               -3.395981E-01   -1.002937E+00          0.000000E+00    0.000000E+00
             YAW                   -2.796040E+00               -3.002027E+00   -2.562244E+00          0.000000E+00    0.000000E+00
             ROLL                   1.204302E+01                1.513194E+01    1.293756E+01          0.000000E+00    0.000000E+00
             URDD1                  0.000000E+00               -2.349813E-14    0.000000E+00          0.000000E+00    0.000000E+00
             AILERON               -1.183942E+02               -1.192126E+02   -1.179562E+02          0.000000E+00    0.000000E+00
             RUDDER                 1.294841E-01                1.146270E-01    2.499947E-01          0.000000E+00    0.000000E+00
             ENG_F                 -1.132953E-15                1.349399E-03    3.644010E-03          0.000000E+00    0.000000E+00
             GIMBAL                 1.460028E-15               -6.746995E-04   -1.822005E-03          0.000000E+00    0.000000E+00

         CONTROL SURFACE = RUDDER        REFERENCE CHORD LENGTH =  1.000000E+00      REFERENCE AREA =  1.000000E+00

             TRIM VARIABLE                RIGID                          ELASTIC                                 INERTIAL
                                                                   RESTRAINED      UNRESTRAINED           RESTRAINED      UNRESTRAINED
             AT REFERENCE           4.308469E-15                4.156866E-15    4.268240E-15          0.000000E+00    0.000000E+00
             ANGLEA                -4.168872E-12               -3.650515E-12   -1.495480E-11          0.000000E+00    0.000000E+00
             URDD3                  0.000000E+00                1.718197E-14    0.000000E+00          0.000000E+00    0.000000E+00
             ELEV                   5.025146E-12                2.519332E-12    3.970683E-12          0.000000E+00    0.000000E+00
             SIDES                 -2.633106E+00               -2.467454E+00   -2.579425E+00          0.000000E+00    0.000000E+00
             YAW                   -4.075425E+00               -4.289193E+00   -4.129695E+00          0.000000E+00    0.000000E+00
             ROLL                  -1.308970E-01               -3.111311E-01   -1.832787E-01          0.000000E+00    0.000000E+00
             URDD1                  0.000000E+00               -8.979477E-16    0.000000E+00          0.000000E+00    0.000000E+00
             AILERON                3.584121E-01                4.176288E-01    3.426807E-01          0.000000E+00    0.000000E+00
             RUDDER                -3.347746E+01               -3.355649E+01   -3.348056E+01          0.000000E+00    0.000000E+00
             ENG_F                 -8.957232E-17                1.537299E-03    1.604890E-03          0.000000E+00    0.000000E+00
             GIMBAL                -2.252759E-18               -7.686494E-04   -8.024450E-04          0.000000E+00    0.000000E+00
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CONTROL SURFACE = RUDDER        REFERENCE CHORD LENGTH =  1.000000E+00      REFERENCE AREA =  1.000000E+00

             TRIM VARIABLE                RIGID                          ELASTIC                                 INERTIAL
                                                                   RESTRAINED      UNRESTRAINED           RESTRAINED      UNRESTRAINED
             AT REFERENCE           4.308469E-15                4.156866E-15    4.268240E-15          0.000000E+00    0.000000E+00
             ANGLEA                -4.168872E-12               -3.650515E-12   -1.495480E-11          0.000000E+00    0.000000E+00
             URDD3                  0.000000E+00                1.718197E-14    0.000000E+00          0.000000E+00    0.000000E+00
             ELEV                   5.025146E-12                2.519332E-12    3.970683E-12          0.000000E+00    0.000000E+00
             SIDES                 -2.633106E+00               -2.467454E+00   -2.579425E+00          0.000000E+00    0.000000E+00
             YAW                   -4.075425E+00               -4.289193E+00   -4.129695E+00          0.000000E+00    0.000000E+00
             ROLL                  -1.308970E-01               -3.111311E-01   -1.832787E-01          0.000000E+00    0.000000E+00
             URDD1                  0.000000E+00               -8.979477E-16    0.000000E+00          0.000000E+00    0.000000E+00
             AILERON                3.584121E-01                4.176288E-01    3.426807E-01          0.000000E+00    0.000000E+00
             RUDDER                -3.347746E+01               -3.355649E+01   -3.348056E+01          0.000000E+00    0.000000E+00
             ENG_F                 -8.957232E-17                1.537299E-03    1.604890E-03          0.000000E+00    0.000000E+00
             GIMBAL                -2.252759E-18               -7.686494E-04   -8.024450E-04          0.000000E+00    0.000000E+00
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1    EXAMPLE HA144F: FSW WITH FUSELAGE, 3 CONTROLS & 2 STOR HA144F
      UNSYMMETRIC FLIGHT CONDITIONS, DOUBLET-LATTICE AERO
0     FULL-SPAN MODEL WITH DISPLACED CANARD                                                      SUBCASE 1
                                       INTERMEDIATE MATRIX ... HP


                                                 COLUMN      1
     1        -3.649423E-18        1.733063E-17     -8.483500E-17       3.527188E-16       4.214065E-18       7.290108E-18        6

                                                 COLUMN      2
     1         5.593610E-02       -5.201215E-12      1.392127E+00       1.653304E-12      -7.447187E-02      -1.195630E-12        6

                                                 COLUMN      3
     1         1.021269E-04       -5.377678E-15     -5.477339E-03       1.025497E-15       1.241935E-04      -1.212025E-15        6

                                                 COLUMN      4
     1         1.329527E-03        1.833952E-12     -6.281645E-03      -4.370893E-13       2.293331E-03       3.933995E-13        6

                                                 COLUMN      5
     1         4.992276E-13       -1.505951E-01      1.347262E-11       1.064169E-01      -7.858075E-13      -2.516001E-02        6

                                                 COLUMN      6
     1        -2.630702E-13        1.510623E-01     -1.157571E-11      -5.458597E-02       8.087151E-13       3.600464E-02        6
                                                  COLUMN      7
     1        -3.544671E-13        1.006466E-02     -7.313114E-12       4.468410E-01       3.979780E-13       7.591589E-03        6

                                                 COLUMN      8
     1        -1.087604E-04       -1.664998E-16 -8.178039E-05       -2.960614E-16       -7.942778E-06       -1.456394E-16        6

                                                 COLUMN      9
     1         1.283108E-13       -5.014083E-03 4.739277E-12       -2.424902E-01       -3.358344E-13       -3.736094E-03        6
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                                                  COLUMN     10
1        8.853881E-14      7.272609E-02     -7.575870E-14     -1.032711E-02      5.726115E-14      1.978044E-02        6

                                                  COLUMN     11
1        2.239035E-05     -1.889754E-03     -3.199698E-04     -4.477881E-04     -1.834362E-05      2.388058E-04        6
                                                  COLUMN     12
1       -2.239035E-05      9.448768E-04      3.199698E-04      2.238941E-04      1.834362E-05     -1.194029E-04        6
INTERMEDIATE MATRIX ... UX


                                                       COLUMN      1
    1        1.000000E+00      3.529960E-03     -1.000000E+00      4.289178E-02      1.396121E-02      1.525178E-02
6
    7       -7.831241E-04      6.904937E-16      0.000000E+00      0.000000E+00      1.000000E+00      1.000000E+00
12

                                                 INTERMEDIATE MATRIX ... UXIFV


                                                       COLUMN      1
    1       -7.485160E-02      3.529960E-03      4.289178E-02      1.396121E-02      1.525178E-02     -7.831241E-04
6
    7        1.814311E-16      2.219353E-16      1.000000E+00      0.000000E+00      0.000000E+00      6.904937E-16
12
   13       -1.000000E+00                                                                                               13

                                 A E R O S T A T I C   D A T A   R E C O V E R Y   O U T P U T   T A B L E S
                             CONFIGURATION = AEROSG2D      XY-SYMMETRY = ASYMMETRIC      XZ-SYMMETRY = ASYMMETRIC
                                        MACH = 9.000000E-01                  Q = 1.200000E+03
                             CHORD = 1.0000E+01           SPAN = 4.0000E+01           AREA = 4.0000E+02

         TRIM ALGORITHM USED: LINEAR TRIM SOLUTION WITHOUT REDUNDANT CONTROL SURFACES.


                                             AEROELASTIC TRIM VARIABLES

                                ID     LABEL               TYPE        TRIM STATUS      VALUE OF UX

                                       INTERCEPT          RIGID BODY          FIXED      1.000000E+00
                               501     ANGLEA             RIGID BODY           FREE      3.529960E-03  RADIANS
                               503     URDD3              RIGID BODY          FIXED     -1.000000E+00  LOAD FACTOR
                               505     ELEV          CONTROL SURFACE           FREE      4.289178E-02  RADIANS
                               511     SIDES              RIGID BODY           FREE      1.396121E-02  RADIANS
                               512     YAW                RIGID BODY           FREE      1.525178E-02  NONDIMEN. RATE
                               513     ROLL               RIGID BODY           FREE     -7.831241E-04  NONDIMEN. RATE
                               517     URDD1              RIGID BODY           FREE      6.904937E-16  LOAD FACTOR
                               518     AILERON       CONTROL SURFACE          FIXED      0.000000E+00  RADIANS
                               519     RUDDER        CONTROL SURFACE          FIXED      0.000000E+00  RADIANS
                               601     ENG_F         GENERAL CONTROL          FIXED      1.000000E+00
                               611     GIMBAL        GENERAL CONTROL          FIXED      1.000000E+00

                                        CONTROL SURFACE POSITION AND HINGE MOMENT RESULTS

                              ACTIVE LIMITS ARE FLAGGED WITH AN (A),  VIOLATED LIMITS ARE FLAGGED WITH A (V).

                                                 POSITION                                           HINGE MOMENT
         CONTROL SURFACE      LOWER LIMIT       VALUE        UPPER LIMIT          LOWER LIMIT        VALUE           UPPER LIMIT
            ELEV            -1.570796E+00   4.289178E-02   1.570796E+00               N/A        1.825997E+04           N/A
            AILERON         -1.570796E+00   0.000000E+00   1.570796E+00               N/A       -7.404354E+01           N/A
            RUDDER          -1.570796E+00   0.000000E+00   1.570796E+00               N/A       -1.186250E+02           N/A

                                           TRANSFORMATION FROM REFERENCE TO WIND AXES:
                                   ANGLE OF ATTACK    =   3.529960E-03 RADIANS (      0.202252 DEGREES)
                                   ANGLE OF SIDESLIP =   1.396121E-02 RADIANS (      0.799918 DEGREES)

                                         { X }           [ -0.999896  0.013961 -0.003530 ]  { X }
                                         { Y }           [  0.013961  0.999903  0.000049 ]  { Y }
                                         { Z }WIND =     [  0.003530  0.000000 -0.999994 ]  { Z }REF

                                     STRUCTURAL  MONITOR POINT TOTAL VEHICLE COEFFICIENTS:
           AXIS          RIGID AIR  +  RESTRAINED INCR.  -  INERTIAL  +   RIGID-APPLIED + RESTRAINED INCR.  =  BALANCE
           ----          ---------     ----------------     --------      -------------   ----------------     -------
     BODY  CX          0.000000E+00     0.000000E+00      1.466475E-33     0.000000E+00     0.000000E+00    -1.466475E-33
     WIND  CD          8.778364E-05     3.237011E-05      1.201537E-04     0.000000E+00     0.000000E+00    -1.355253E-20

     BODY  CY          6.643117E-04    -6.643117E-04     -8.507724E-17     0.000000E+00     0.000000E+00    -2.092038E-18
     WIND  CY-WIND     6.631508E-04    -6.648284E-04     -1.677600E-06     0.000000E+00     0.000000E+00    -2.091960E-18

     BODY  CZ         -2.224308E-02    -1.179859E-02     -3.404167E-02     0.000000E+00     0.000000E+00    -6.938894E-18
     WIND  CL          2.224294E-02     1.179852E-02      3.404145E-02     0.000000E+00     0.000000E+00     6.938894E-18

     BODY  CMX         2.676030E-04    -2.676030E-04     -4.579783E-16     0.000000E+00     0.000000E+00     3.512681E-19
     WIND  CM-ROLL    -2.685774E-04     1.614150E-04     -1.071624E-04     0.000000E+00     0.000000E+00    -3.794708E-19

     BODY  CMY        -1.192786E-04    -7.556695E-03     -7.675974E-03     0.000000E+00     0.000000E+00    -1.734723E-18
     WIND  CM-PITCH   -1.155403E-04    -7.559686E-03     -7.675226E-03     0.000000E+00     0.000000E+00    -1.734723E-18

     BODY  CMZ        -1.878432E-04     1.878432E-04      2.084352E-17     0.000000E+00     0.000000E+00    -5.950536E-19
     WIND  CM-YAW      1.887867E-04    -1.887867E-04     -2.246004E-17     0.000000E+00     0.000000E+00     5.962898E-19
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                              AERODYNAMIC MONITOR POINT TOTAL VEHICLE COEFFICIENTS:
      AXIS         RIGID AIR  +  RESTRAINED INCR.  -  INERTIAL   +    RIGID-APPLIED + RESTRAINED INCR.  =  BALANCE
      ----         ---------     ----------------     --------        -------------   ----------------     -------
BODY  CX          0.000000E+00    0.000000E+00          N/A               N/A          0.000000E+00     0.000000E+00
WIND  CD          8.778364E-05    3.237011E-05          N/A               N/A          0.000000E+00     1.201537E-04

BODY  CY          6.643117E-04   -6.643117E-04          N/A               N/A          0.000000E+00    -8.510987E-17
WIND  CY-WIND     6.631508E-04   -6.648284E-04          N/A               N/A          0.000000E+00    -1.677600E-06

BODY  CZ         -2.224308E-02   -1.179859E-02          N/A               N/A          0.000000E+00    -3.404167E-02
WIND  CL          2.224294E-02    1.179852E-02          N/A               N/A          0.000000E+00     3.404145E-02

BODY  CMX        -1.230220E-04   -2.676030E-04          N/A               N/A          0.000000E+00    -3.906250E-04
WIND  CM-ROLL     1.258919E-04    1.614150E-04          N/A               N/A          0.000000E+00     2.873070E-04

BODY  CMY        -1.192786E-04   -7.556695E-03          N/A               N/A          0.000000E+00    -7.675974E-03
WIND  CM-PITCH   -1.210479E-04   -7.559686E-03          N/A               N/A          0.000000E+00    -7.680734E-03

BODY  CMZ        -1.288494E-03    1.878432E-04          N/A               N/A          0.000000E+00    -1.100651E-03
WIND  CM-YAW      1.288052E-03   -1.887867E-04          N/A               N/A          0.000000E+00     1.099265E-03
A E R O S T A T I C   D A T A   R E C O V E R Y   O U T P U T   T A B L E S
                         CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = ASYMMETRIC
                                           MACH = 9.000000E-01                 Q = 1.200000E+03
                         CHORD = 1.0000E+01          SPAN = 4.0000E+01          AREA = 4.0000E+02


                                             AERODYNAMIC FORCES ON THE AERODYNAMIC ELEMENTS

    GROUP  GRID ID  LABEL        T1              T2              T3              R1              R2              R3
        1    11000    LS    0.000000E+00    0.000000E+00    3.589003E+02    0.000000E+00    2.243127E+02    0.000000E+00
        1    11001    LS    0.000000E+00    0.000000E+00    3.214696E+01    0.000000E+00    2.009185E+01    0.000000E+00
        1    11002    LS    0.000000E+00    0.000000E+00    8.388439E+00    0.000000E+00    5.242774E+00    0.000000E+00
        1    11003    LS    0.000000E+00    0.000000E+00    1.008176E+01    0.000000E+00    6.301103E+00    0.000000E+00
        1    11004    LS    0.000000E+00    0.000000E+00    1.649995E+03    0.000000E+00    1.031247E+03    0.000000E+00
        1    11005    LS    0.000000E+00    0.000000E+00    1.504934E+02    0.000000E+00    9.405836E+01    0.000000E+00
        1    11006    LS    0.000000E+00    0.000000E+00    4.597805E+01    0.000000E+00    2.873628E+01    0.000000E+00
        1    11007    LS    0.000000E+00    0.000000E+00    4.930405E+01    0.000000E+00    3.081503E+01    0.000000E+00
        1    21104    LS    0.000000E+00    0.000000E+00   -1.596285E+02    0.000000E+00   -9.976781E+01    0.000000E+00
        1    21105    LS    0.000000E+00    0.000000E+00    4.829815E+01    0.000000E+00    3.018635E+01    0.000000E+00
        1    21106    LS    0.000000E+00    0.000000E+00    2.199506E+01    0.000000E+00    1.374691E+01    0.000000E+00
        1    21107    LS    0.000000E+00    0.000000E+00    1.719909E+01    0.000000E+00    1.074943E+01    0.000000E+00
        1    21108    LS    0.000000E+00    0.000000E+00    6.805459E+02    0.000000E+00    4.253412E+02    0.000000E+00
        1    21109    LS    0.000000E+00    0.000000E+00    8.443419E+01    0.000000E+00    5.277137E+01    0.000000E+00
        1    21110    LS    0.000000E+00    0.000000E+00    4.132866E+01    0.000000E+00    2.583041E+01    0.000000E+00
        1    21111    LS    0.000000E+00    0.000000E+00    2.062229E+01    0.000000E+00    1.288893E+01    0.000000E+00
        1    21112    LS    0.000000E+00    0.000000E+00    7.355162E+02    0.000000E+00    4.596976E+02    0.000000E+00
        1    21113    LS    0.000000E+00    0.000000E+00    1.737170E+02    0.000000E+00    1.085731E+02    0.000000E+00
        1    21114    LS    0.000000E+00    0.000000E+00    7.353120E+01    0.000000E+00    4.595700E+01    0.000000E+00
        1    21115    LS    0.000000E+00    0.000000E+00    3.586226E+01    0.000000E+00    2.241391E+01    0.000000E+00
        1    31116    LS    0.000000E+00    0.000000E+00    7.187565E+02    0.000000E+00    4.492228E+02    0.000000E+00
        1    31117    LS    0.000000E+00    0.000000E+00    2.608375E+02    0.000000E+00    1.630234E+02    0.000000E+00
        1    31118    LS    0.000000E+00    0.000000E+00    8.503888E+01    0.000000E+00    5.314930E+01    0.000000E+00
        1    31119    LS    0.000000E+00    0.000000E+00    2.329014E+01    0.000000E+00    1.455633E+01    0.000000E+00
        1    31120    LS    0.000000E+00    0.000000E+00    6.159141E+02    0.000000E+00    3.849463E+02    0.000000E+00
        1    31121    LS    0.000000E+00    0.000000E+00    2.392085E+02    0.000000E+00    1.495053E+02    0.000000E+00
        1    31122    LS    0.000000E+00    0.000000E+00    1.101769E+02    0.000000E+00    6.886055E+01    0.000000E+00
        1    31123    LS    0.000000E+00    0.000000E+00    3.589733E+01    0.000000E+00    2.243583E+01    0.000000E+00
        1    31124    LS    0.000000E+00    0.000000E+00    4.959560E+02    0.000000E+00    3.099725E+02    0.000000E+00
        1    31125    LS    0.000000E+00    0.000000E+00    1.993326E+02    0.000000E+00    1.245829E+02    0.000000E+00
        1    31126    LS    0.000000E+00    0.000000E+00    1.051087E+02    0.000000E+00    6.569295E+01    0.000000E+00
        1    31127    LS    0.000000E+00    0.000000E+00    4.399071E+01    0.000000E+00    2.749420E+01    0.000000E+00

 *** LABEL NOTATIONS:  LS = LIFTING SURFACE,   ZSB =  Z SLENDER BODY ELEMENT,  YSB =  Y SLENDER BODY ELEMENT,
                                                 ZYSB = ZY SLENDER BODY ELEMENT, EXTA = EXTERNAL AERO.

                                         AERODYNAMIC FORCES ON THE AERODYNAMIC ELEMENTS

    GROUP  GRID ID  LABEL        T1              T2              T3              R1              R2              R3
        1    31128    LS    0.000000E+00    0.000000E+00    3.391070E+02    0.000000E+00    2.119419E+02    0.000000E+00
        1    31129    LS    0.000000E+00    0.000000E+00    1.340374E+02    0.000000E+00    8.377338E+01    0.000000E+00
        1    31130    LS    0.000000E+00    0.000000E+00    7.643363E+01    0.000000E+00    4.777102E+01    0.000000E+00
        1    31131    LS    0.000000E+00    0.000000E+00    3.826395E+01    0.000000E+00    2.391497E+01    0.000000E+00
        1    32000    LS    0.000000E+00    0.000000E+00    1.483237E+03    0.000000E+00    9.270232E+02    0.000000E+00
        1    32001    LS    0.000000E+00    0.000000E+00    1.509841E+02    0.000000E+00    9.436507E+01    0.000000E+00
        1    32002    LS    0.000000E+00    0.000000E+00    7.120495E+01    0.000000E+00    4.450310E+01    0.000000E+00
        1    32003    LS    0.000000E+00    0.000000E+00    5.357522E+01    0.000000E+00    3.348452E+01    0.000000E+00
        1    32004    LS    0.000000E+00    0.000000E+00    3.092994E+02    0.000000E+00    1.933121E+02    0.000000E+00
        1    32005    LS    0.000000E+00    0.000000E+00    3.277537E+01    0.000000E+00    2.048461E+01    0.000000E+00
        1    32006    LS    0.000000E+00    0.000000E+00    1.666810E+01    0.000000E+00    1.041756E+01    0.000000E+00
        1    32007    LS    0.000000E+00    0.000000E+00    1.126017E+01    0.000000E+00    7.037604E+00    0.000000E+00
        1    42100    LS    0.000000E+00    0.000000E+00    1.948320E+02    0.000000E+00    1.217700E+02    0.000000E+00
        1    42101    LS    0.000000E+00    0.000000E+00    1.088696E+02    0.000000E+00    6.804349E+01    0.000000E+00
        1    42102    LS    0.000000E+00    0.000000E+00    8.231330E+01    0.000000E+00    5.144581E+01    0.000000E+00
        1    42103    LS    0.000000E+00    0.000000E+00    5.749819E+01    0.000000E+00    3.593637E+01    0.000000E+00
1     42104    LS    0.000000E+00    0.000000E+00    3.077014E+02    0.000000E+00    1.923134E+02    0.000000E+00
        1    42105    LS    0.000000E+00    0.000000E+00    1.661729E+02    0.000000E+00    1.038581E+02    0.000000E+00
        1    42106    LS    0.000000E+00    0.000000E+00    1.132218E+02    0.000000E+00    7.076360E+01    0.000000E+00
        1    42107    LS    0.000000E+00    0.000000E+00    6.942787E+01    0.000000E+00    4.339242E+01    0.000000E+00
        1    42108    LS    0.000000E+00    0.000000E+00    4.124448E+02    0.000000E+00    2.577780E+02    0.000000E+00
        1    42109    LS    0.000000E+00    0.000000E+00    2.003920E+02    0.000000E+00    1.252450E+02    0.000000E+00
        1    42110    LS    0.000000E+00    0.000000E+00    1.193762E+02    0.000000E+00    7.461012E+01    0.000000E+00
        1    42111    LS    0.000000E+00    0.000000E+00    6.980431E+01    0.000000E+00    4.362769E+01    0.000000E+00
        1    42112    LS    0.000000E+00    0.000000E+00    5.255739E+02    0.000000E+00    3.284837E+02    0.000000E+00
        1    42113    LS    0.000000E+00    0.000000E+00    1.716529E+02    0.000000E+00    1.072830E+02    0.000000E+00
        1    42114    LS    0.000000E+00    0.000000E+00    1.198459E+02    0.000000E+00    7.490367E+01    0.000000E+00
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1    42115   LS     0.000000E+00      0.000000E+00      6.547859E+01      0.000000E+00      4.092412E+01      0.000000E+00
       1     52116   LS     0.000000E+00      0.000000E+00      6.906633E+02      0.000000E+00      4.316645E+02      0.000000E+00
       1     52117   LS     0.000000E+00      0.000000E+00      2.706936E+02      0.000000E+00      1.691835E+02      0.000000E+00
       1     52118   LS     0.000000E+00      0.000000E+00      7.498996E+01      0.000000E+00      4.686873E+01      0.000000E+00

         *** LABEL NOTATIONS:  LS = LIFTING SURFACE,   ZSB =  Z SLENDER BODY ELEMENT,  YSB =  Y SLENDER BODY ELEMENT,
                                                       ZYSB = ZY SLENDER BODY ELEMENT, EXTA = EXTERNAL AERO.

AERODYNAMIC FORCES ON THE AERODYNAMIC ELEMENTS

    GROUP  GRID ID  LABEL          T1                T2                T3                R1                R2                R3
       1     52119   LS     0.000000E+00      0.000000E+00      3.900170E+01      0.000000E+00      2.437606E+01      0.000000E+00
       1     52120   LS     0.000000E+00      0.000000E+00      6.866258E+02      0.000000E+00      4.291411E+02      0.000000E+00
       1     52121   LS     0.000000E+00      0.000000E+00      1.195701E+02      0.000000E+00      7.473133E+01      0.000000E+00
       1     52122   LS     0.000000E+00      0.000000E+00      5.806138E+01      0.000000E+00      3.628837E+01      0.000000E+00
       1     52123   LS     0.000000E+00      0.000000E+00      2.555910E+01      0.000000E+00      1.597444E+01      0.000000E+00
       1     52124   LS     0.000000E+00      0.000000E+00     -6.954495E+01      0.000000E+00     -4.346560E+01      0.000000E+00
       1     52125   LS     0.000000E+00      0.000000E+00      7.805720E+01      0.000000E+00      4.878575E+01      0.000000E+00
       1     52126   LS     0.000000E+00      0.000000E+00      4.790444E+01      0.000000E+00      2.994027E+01      0.000000E+00
       1     52127   LS     0.000000E+00      0.000000E+00      8.571890E+00      0.000000E+00      5.357432E+00      0.000000E+00
       1     53100   LS     0.000000E+00      0.000000E+00     -6.670837E+01      0.000000E+00     -4.169273E+01      0.000000E+00
       1     53101   LS     0.000000E+00      0.000000E+00      6.957136E+01      0.000000E+00      4.348210E+01      0.000000E+00
       1     53102   LS     0.000000E+00      0.000000E+00      7.592171E+01      0.000000E+00      4.745107E+01      0.000000E+00
       1     53103   LS     0.000000E+00      0.000000E+00      5.904859E+01      0.000000E+00      3.690537E+01      0.000000E+00
       1     53104   LS     0.000000E+00      0.000000E+00     -1.220919E+02      0.000000E+00     -7.630745E+01      0.000000E+00
       1     53105   LS     0.000000E+00      0.000000E+00      7.083646E+01      0.000000E+00      4.427279E+01      0.000000E+00
       1     53106   LS     0.000000E+00      0.000000E+00      9.668223E+01      0.000000E+00      6.042639E+01      0.000000E+00
       1     53107   LS     0.000000E+00      0.000000E+00      7.919073E+01      0.000000E+00      4.949420E+01      0.000000E+00
       1     53108   LS     0.000000E+00      0.000000E+00     -1.711671E+02      0.000000E+00     -1.069794E+02      0.000000E+00
       1     53109   LS     0.000000E+00      0.000000E+00      6.551968E+01      0.000000E+00      4.094980E+01      0.000000E+00
       1     53110   LS     0.000000E+00      0.000000E+00      9.876813E+01      0.000000E+00      6.173008E+01      0.000000E+00
       1     53111   LS     0.000000E+00      0.000000E+00      8.092937E+01      0.000000E+00      5.058085E+01      0.000000E+00
       1     53500   LS     0.000000E+00      0.000000E+00     -4.505647E+01      0.000000E+00     -2.816029E+01      0.000000E+00
       1     53501   LS     0.000000E+00      0.000000E+00      1.042888E+01      0.000000E+00      6.518053E+00      0.000000E+00
       1     53600   LS     0.000000E+00      0.000000E+00     -1.309016E+02      0.000000E+00     -8.181352E+01      0.000000E+00
       1     53601   LS     0.000000E+00      0.000000E+00      1.512061E+01      0.000000E+00      9.450379E+00      0.000000E+00
       1     54000   ZYSB   0.000000E+00     -2.463759E+02      3.398932E+01      0.000000E+00      0.000000E+00      0.000000E+00
       1     54001   ZYSB   0.000000E+00     -2.781472E+02      5.833413E+01      0.000000E+00      0.000000E+00      0.000000E+00
       1     54002   ZYSB   0.000000E+00     -3.394670E+01      2.889011E+02      0.000000E+00      0.000000E+00      0.000000E+00
       1     54003   ZYSB   0.000000E+00      7.885488E+01      7.433139E+02      0.000000E+00      0.000000E+00      0.000000E+00
       1     54004   ZYSB   0.000000E+00      1.146721E+02      2.853289E+02      0.000000E+00      0.000000E+00      0.000000E+00
       1     54005   ZYSB   0.000000E+00      1.048025E+01      2.668225E+02      0.000000E+00      0.000000E+00      0.000000E+00

         *** LABEL NOTATIONS:  LS = LIFTING SURFACE,   ZSB =  Z SLENDER BODY ELEMENT,  YSB =  Y SLENDER BODY ELEMENT,
                                                       ZYSB = ZY SLENDER BODY ELEMENT, EXTA = EXTERNAL AERO.
AERODYNAMIC FORCES ON THE AERODYNAMIC ELEMENTS

    GROUP  GRID ID  LABEL          T1                T2                T3                R1                R2                R3
       1     54006   ZYSB   0.000000E+00      9.730283E+01      1.916196E+02      0.000000E+00      0.000000E+00      0.000000E+00
       1     54007   ZYSB   0.000000E+00      2.671997E+02      4.358731E+01      0.000000E+00      0.000000E+00      0.000000E+00
       1     54510   ZYSB   0.000000E+00     -1.758570E+01      2.759998E+00      0.000000E+00      0.000000E+00      0.000000E+00
       1     54511   ZYSB   0.000000E+00     -1.127595E+00      6.200458E+00      0.000000E+00      0.000000E+00      0.000000E+00
       1     54512   ZYSB   0.000000E+00      8.280031E+00      3.737971E+00      0.000000E+00      0.000000E+00      0.000000E+00
       1     54513   ZYSB   0.000000E+00      1.224696E+01     -1.013682E+01      0.000000E+00      0.000000E+00      0.000000E+00
       1     64610   ZYSB   0.000000E+00     -2.914938E+01      6.524661E+00      0.000000E+00      0.000000E+00      0.000000E+00
       1     64611   ZYSB   0.000000E+00     -3.716128E+01      4.061339E+00      0.000000E+00      0.000000E+00      0.000000E+00
       1     64612   ZYSB   0.000000E+00      3.596575E+00      4.254717E+00      0.000000E+00      0.000000E+00      0.000000E+00
       1     64613   ZYSB   0.000000E+00      9.255583E+00     -1.066479E+01      0.000000E+00      0.000000E+00      0.000000E+00

         *** LABEL NOTATIONS:  LS = LIFTING SURFACE,   ZSB =  Z SLENDER BODY ELEMENT,  YSB =  Y SLENDER BODY ELEMENT,
                                                       ZYSB = ZY SLENDER BODY ELEMENT, EXTA = EXTERNAL AERO.
S T R U C T U R A L    M O N I T O R    P O I N T    I N T E G R A T E D    L O A D S
                        CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = ASYMMETRIC
                                          MACH = 9.000000E-01                Q = 1.200000E+03

        CONTROLLER STATE:
        ANGLEA    =    3.5300E-03       URDD3     =  -1.0000E+00        ELEV      =    4.2892E-02        SIDES     =    1.3961E-02
        YAW       =    1.5252E-02       ROLL      =  -7.8312E-04        ENG_F     =    1.0000E+00        GIMBAL    =    1.0000E+00

        MONITOR POINT NAME = AEROSG2D           COMPONENT =                       CLASS = COEFFICIENT
        LABEL = Full Vehicle Integrated Loads
         CP =       100           X =  0.00000E+00          Y =  0.00000E+00          Z =  0.00000E+00          CD =       100

          AXIS      RIGID AIR       ELASTIC REST.      INERTIAL      RIGID APPLIED    REST. APPLIED
          ----    -------------    -------------    -------------    -------------    -------------
           CX     0.000000E+00     0.000000E+00     7.039082E-28     0.000000E+00     0.000000E+00
           CY     3.188696E+02    -4.184125E-11    -4.083708E-11     0.000000E+00     0.000000E+00
           CZ    -1.067668E+04    -1.634000E+04    -1.634000E+04     0.000000E+00     0.000000E+00
           CMX    5.137977E+03    -8.786439E-09    -8.793184E-09     0.000000E+00     0.000000E+00
           CMY   -5.725371E+02    -3.684467E+04    -3.684467E+04     0.000000E+00     0.000000E+00
           CMZ   -3.606590E+03     3.887706E-10     4.001957E-10     0.000000E+00     0.000000E+00

        MONITOR POINT NAME = ELEV               COMPONENT = 50501                 CLASS = HINGE MOMENT
        LABEL = ELEV     - Control Surface Hinge Moment
         CP =        90           X =  0.00000E+00          Y =  0.00000E+00          Z =  0.00000E+00          CD =        90

          AXIS      RIGID AIR       ELASTIC REST.      INERTIAL      RIGID APPLIED    REST. APPLIED
          ----    -------------    -------------    -------------    -------------    -------------
           CMY    4.408311E+03     4.401712E+03    -5.000000E+01     0.000000E+00     0.000000E+00

        MONITOR POINT NAME = ELEV               COMPONENT = 50502                 CLASS = HINGE MOMENT
        LABEL = ELEV     - Control Surface Hinge Moment (Second Axis)
         CP =        90           X =  0.00000E+00          Y =  0.00000E+00          Z =  0.00000E+00          CD =        90

          AXIS      RIGID AIR       ELASTIC REST.      INERTIAL      RIGID APPLIED    REST. APPLIED
          ----    -------------    -------------    -------------    -------------    -------------
           CMY    3.944602E+03     3.940960E+03    -5.000000E+01     0.000000E+00     0.000000E+00
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 A E R O D Y N A M I C   M O N I T O R   P O I N T   I N T E G R A T E D   L O A D S
                        CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = ASYMMETRIC
                                          MACH = 9.000000E-01                 Q = 1.200000E+03

        CONTROLLER STATE:
        ANGLEA    =   3.5300E-03        URDD3    =  -1.0000E+00        ELEV     =   4.2892E-02        SIDES    =   1.3961E-02
        YAW       =   1.5252E-02        ROLL     =  -7.8312E-04        ENG_F    =   1.0000E+00        GIMBAL   =   1.0000E+00

        MONITOR POINT NAME = AEROSG2D          COMPONENT =                    CLASS = COEFFICIENT
        LABEL = Full Vehicle Integrated Loads
         CP =       100           X =  0.00000E+00          Y =  0.00000E+00          Z =  0.00000E+00          CD =       100

          AXIS      RIGID AIR       ELASTIC REST.
          ----    -------------    -------------
           CX      0.000000E+00     0.000000E+00
           CY      3.188696E+02    -4.082684E-11
           CZ     -1.067668E+04    -1.634000E+04
           CMX    -2.362023E+03    -7.500000E+03
           CMY    -5.725371E+02    -3.684467E+04
           CMZ    -2.473909E+04    -2.113250E+04

        MONITOR POINT NAME = AILERON           COMPONENT = 1100               CLASS = HINGE MOMENT
        LABEL = AILERON  - Control Surface Hinge Moment
         CP =       110           X =  0.00000E+00          Y =  0.00000E+00          Z =  0.00000E+00          CD =       110

          AXIS      RIGID AIR       ELASTIC REST.
          ----    -------------    -------------
           CMY     2.316001E+01     9.023962E+01

        MONITOR POINT NAME = AILERON           COMPONENT = 2100               CLASS = HINGE MOMENT
        LABEL = AILERON  - Control Surface Hinge Moment (Second Axis)
         CP =       210           X =  0.00000E+00          Y =  0.00000E+00          Z =  0.00000E+00          CD =       210

          AXIS      RIGID AIR       ELASTIC REST.
          ----    -------------    -------------
           CMY    -1.019630E+02    -1.642832E+02

        MONITOR POINT NAME = ELEV              COMPONENT = 1000               CLASS = HINGE MOMENT
        LABEL = ELEV     - Control Surface Hinge Moment
         CP =        90           X =  0.00000E+00          Y =  0.00000E+00          Z =  0.00000E+00          CD =        90

          AXIS      RIGID AIR       ELASTIC REST.
          ----    -------------    -------------
           CMY     8.925064E+03     8.911810E+03

        MONITOR POINT NAME = ELEV              COMPONENT = 2000               CLASS = HINGE MOMENT
        LABEL = ELEV     - Control Surface Hinge Moment (Second Axis)
         CP =        90           X =  0.00000E+00          Y =  0.00000E+00          Z =  0.00000E+00          CD =        90

          AXIS      RIGID AIR       ELASTIC REST.
          ----    -------------    -------------
           CMY     7.936528E+03     7.929365E+03

        MONITOR POINT NAME = RUDDER            COMPONENT = 3000               CLASS = HINGE MOMENT
        LABEL = RUDDER   - Control Surface Hinge Moment
         CP =       301           X =  0.00000E+00          Y =  0.00000E+00          Z =  0.00000E+00          CD =       301

          AXIS      RIGID AIR       ELASTIC REST.
          ----    -------------    -------------
           CMY    -1.185796E+02    -1.186250E+02

0 RESULTANTS ABOUT      1000 IN SUPERELEMENT BASIC SYSTEM COORDINATES.

0                                                   TRIMMED  OLOAD RESULTANT
  SUBCASE/
  DAREA ID         T1             T2             T3             R1             R2             R3
0        1  -1.8932662E-29 -2.2737368E-12  8.3062446E-12 -3.4034997E-12 -2.9704239E-11  5.7154855E-12

0 RESULTANTS ABOUT      1000 IN SUPERELEMENT BASIC SYSTEM COORDINATES.

0                                                   MPCFORCE RESULTANT
  SUBCASE/    LOAD
  DAREA ID    TYPE        T1            T2            T3            R1            R2            R3
0        1     FX    1.703940E-28     ----          ----          ----      -2.485777E-13  3.344770E-27
               FY        ----      -1.136868E-13    ----       2.273737E-13     ----      -2.703649E+03
               FZ        ----          ----      -1.492140E-13 -6.892265E-13 -2.663962E+04     ----
               MX        ----          ----          ----       0.000000E+00     ----          ----
               MY        ----          ----          ----          ----       2.663962E+04     ----
               MZ        ----          ----          ----          ----          ----       2.703649E+03
            TOTALS  1.703940E-28 -1.136868E-13 -1.492140E-13 -4.618528E-13  3.637979E-12 -1.364242E-12

                                                         L O A D   V E C T O R

      POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
            88      G      0.0            0.0            1.104625E+03   7.552539E+02   3.940960E+03   0.0
            89      G      0.0            0.0            1.024380E+03  -6.121437E+02   3.988405E+03   0.0
            90      G      0.0            5.000000E+03   0.0            0.0            0.0            0.0
            91      G      0.0            0.0            1.114563E+03   6.619976E+02   4.510097E+03   0.0
            92      G      0.0            0.0            1.190725E+03  -8.141832E+02   4.401712E+03   0.0
            97      G      2.071481E-12  -5.341674E+02  -2.925109E+03   0.0            0.0            0.0
            98      G      2.071481E-12   7.099428E+01  -2.057735E+03   0.0            0.0            0.0
            99      G      2.071481E-12   5.374116E+01  -2.293706E+03   0.0            0.0            0.0
           100      G      2.071481E-12   3.034552E+02  -2.594927E+03   0.0            0.0            0.0
           111      G      4.142962E-13   1.573849E-24   8.408417E+02   0.0            0.0            0.0
           112      G      2.761975E-13   2.731562E-24  -1.261437E+03   0.0            0.0            0.0
           115      G      0.0           -1.043287E+02   1.497595E+03   0.0            0.0            0.0
           121      G     -2.920939E-12  -7.117247E+02   2.958624E+03   0.0            0.0            0.0
122      G     -1.947293E-12   1.023749E+02  -9.118744E+02   0.0            0.0            0.0

           150      G      0.0           -2.542926E+03   1.028823E+01   0.0            0.0            0.0
           151      G      0.0            3.319735E+01  -7.726621E+00   0.0            0.0            0.0
           211      G      4.142962E-13   1.613777E-24   1.046301E+03   0.0            0.0            0.0
           212      G      2.761975E-13   2.725305E-24  -1.256838E+03   0.0            0.0            0.0
           215      G      0.0           -5.477095E+00   1.485256E+03   0.0            0.0            0.0
           221      G      7.049766E-13   4.891911E+02   1.845955E+03   0.0            0.0            0.0
           222      G      4.699844E-13  -1.479525E+01  -4.739763E+02   0.0            0.0            0.0
           250      G      0.0           -2.589971E+03   1.284374E+01   0.0            0.0            0.0
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 251      G      0.0          -2.080800E+00  -8.667818E+00   0.0           0.0           0.0
        311      G     -3.683615E-12  -1.594143E+02  -6.000000E+01   0.0           0.0           0.0
        312      G     -2.455744E-12   6.119320E+02  -4.000000E+01   0.0           0.0           0.0
        881      G      1.380987E-14   7.145248E-30  -2.000000E+01   0.0           0.0           0.0
        882      G      2.761975E-14  -1.429050E-29  -4.000000E+01   0.0           0.0           0.0
        891      G      1.380987E-14   1.546530E-30  -2.000000E+01   0.0           0.0           0.0
        892      G      2.761975E-14  -3.093061E-30  -4.000000E+01   0.0           0.0           0.0
        911      G      1.380987E-14  -1.546530E-30  -2.000000E+01   0.0           0.0           0.0
        912      G      2.761975E-14   3.093061E-30  -4.000000E+01   0.0           0.0           0.0
        921      G      1.380987E-14  -7.145248E-30  -2.000000E+01   0.0           0.0           0.0
        922      G      2.761975E-14   1.429050E-29  -4.000000E+01   0.0           0.0           0.0

                                F O R C E S   I N   B A R   E L E M E N T S        ( C B A R )
0    ELEMENT         BEND-MOMENT END-A            BEND-MOMENT END-B                - SHEAR -               AXIAL
       ID.         PLANE 1       PLANE 2        PLANE 1       PLANE 2        PLANE 1       PLANE 2         FORCE          TORQUE
         89    -7.552539E+02 -2.019484E-28   2.378620E+03  1.242889E-13  -1.044625E+03 -4.142962E-14   7.145248E-30  -3.990960E+03
         90     2.990764E+03  1.242889E-13   7.008773E+03  2.900074E-13  -2.009004E+03 -8.285924E-14   8.691779E-30  -8.029365E+03
         91     7.610567E+03  2.900074E-13   3.239990E+03  1.242889E-13   2.185288E+03  8.285924E-14   8.691779E-30   9.011810E+03
         92     2.577992E+03  1.242889E-13  -8.141832E+02 -3.029226E-28   1.130725E+03  4.142962E-14   7.145248E-30   4.451712E+03
        101     2.910383E-11  3.637979E-12  -2.925109E+04  5.341674E+03   2.925109E+03 -5.341674E+02  -2.071481E-12   0.0
        102    -2.925109E+04  5.341674E+03  -5.416531E+04  7.657540E+03   4.982844E+03 -4.631731E+02  -4.142962E-12   0.0
        103    -4.106689E+04 -1.502659E+04  -7.188946E+04 -6.093227E+04   3.082257E+03  4.590568E+03   2.578120E-09  -6.017940E+02
        104    -3.712414E+04  7.657540E+03  -4.106689E+04 -1.502659E+04   7.885513E+02  4.536827E+03   2.580192E-09  -6.017940E+02
        110     5.510391E+04 -3.511926E+04   3.705415E+04 -2.581409E+04   3.126311E+03 -1.611703E+03  -2.791553E+03   1.455361E+04
        115     3.442630E+04 -2.581409E+04   1.394823E+04 -1.650892E+04   3.546906E+03 -1.611703E+03  -2.791553E+03   1.000205E+04
        120     1.718274E+04 -2.360478E+03   4.838121E+03 -5.752470E+02   2.106784E+03 -3.046748E+02  -1.706641E+02   8.604280E+03
        150     1.164153E-10 -9.313226E-10   5.144116E+01  1.271463E+04  -1.028823E+01 -2.542926E+03   0.0            0.0
        151    -5.144116E+01 -3.725290E-09  -5.144116E+01 -3.764593E+03  -1.862645E-09  2.509729E+03  -2.561611E+00  -1.271463E+04
        210     4.933527E+04 -2.257834E+04   3.403045E+04 -1.644938E+04   2.650874E+03 -1.061566E+03   1.838688E+03  -7.883622E+03
        215     3.115152E+04 -1.644938E+04   1.463116E+04 -1.032043E+04   2.861411E+03 -1.061566E+03   1.838688E+03  -2.897179E+03
        220     1.123188E+04  1.774122E+03   2.899914E+03  3.842698E+02   1.421967E+03  2.371978E+02  -1.706641E+02  -5.164143E+03
        250    -4.656613E-10 -1.862645E-09   6.421872E+01  1.294986E+04  -1.284374E+01 -2.589971E+03   0.0            0.0
        251    -6.421872E+01 -7.450581E-09  -6.421872E+01 -3.888078E+03  -5.587935E-09  2.592052E+03  -4.175926E+00  -1.294986E+04
        310    -2.386750E+02 -3.576794E+03   5.000000E+01 -9.641826E+02  -4.999998E+01 -4.525177E+02  -8.660255E+01   1.670014E+03

                                      G R I D   P O I N T   F O R C E   B A L A N C E

   POINT-ID    ELEMENT-ID     SOURCE             T1             T2             T3             R1             R2             R3
        88                  APP-LOAD       0.0            0.0            1.104625E+03   7.552539E+02   3.940960E+03   0.0
        88                  F-OF-MPC       4.142962E-14  -7.145248E-30  -6.000000E+01   0.0            5.000000E+01  -5.358936E-29
        88            89    BAR           -4.142962E-14   7.145248E-30  -1.044625E+03  -7.552539E+02  -3.990960E+03   1.009742E-28
        88                  *TOTALS*      -1.199069E-28  -1.401298E-45  -4.320100E-12  -4.320100E-12  -9.094947E-13   4.738483E-29
0       89                  APP-LOAD       0.0            0.0            1.024380E+03  -6.121437E+02   3.988405E+03   0.0
        89                  F-OF-MPC      -4.142962E-14   7.145248E-30  -2.069004E+03   2.990764E+03  -7.979365E+03  -1.242889E-13
        89            89    BAR            4.142962E-14  -7.145248E-30   1.044625E+03  -2.378620E+03   3.990960E+03   1.242889E-13
        89                  *TOTALS*       1.262177E-29   1.401298E-45   0.0            0.0            0.0            1.262177E-28
0       90                  APP-LOAD       0.0            5.000000E+03   0.0            0.0            0.0            0.0
        90            90    BAR            8.285924E-14  -8.691779E-30   2.009004E+03  -7.008773E+03   8.029365E+03   2.900074E-13
        90            91    BAR            8.285924E-14   8.691779E-30   2.185288E+03   7.610567E+03   9.011810E+03  -2.900074E-13
        90           102    BAR            4.142962E-12  -4.631731E+02  -4.982844E+03   0.0           -5.416531E+04   7.657540E+03
        90           104    BAR            2.580192E-09  -4.536827E+03   7.885513E+02  -6.017940E+02   3.712414E+04  -7.657540E+03
        90                  *TOTALS*       2.584500E-09  -2.051820E-09  -4.878530E-09  -1.187800E-08   4.544563E-08  -7.375729E-08
0       91                  APP-LOAD       0.0            0.0            1.114563E+03   6.619976E+02   4.510097E+03   0.0
        91                  F-OF-MPC      -4.142962E-14  -7.145248E-30  -2.245288E+03  -3.239990E+03  -8.961810E+03   1.242889E-13
        91            92    BAR            4.142962E-14   7.145248E-30   1.130725E+03   2.577992E+03   4.451712E+03  -1.242889E-13
        91                  *TOTALS*       6.310887E-29   0.0           -1.364242E-12   2.273737E-12  -9.094947E-13  -2.524355E-29
0       92                  APP-LOAD       0.0            0.0            1.190725E+03  -8.141832E+02   4.401712E+03   0.0
        92                  F-OF-MPC       4.142962E-14   7.145248E-30  -6.000000E+01   0.0            5.000000E+01   5.358936E-29
        92            92    BAR           -4.142962E-14  -7.145248E-30  -1.130725E+03   8.141832E+02  -4.451712E+03  -1.009742E-28
        92                  *TOTALS*      -1.199069E-28   1.401298E-45   5.684342E-12  -3.524292E-12   0.0           -4.738483E-29
0       97                  APP-LOAD       2.071481E-12  -5.341674E+02  -2.925109E+03   0.0            0.0            0.0
        97           101    BAR           -2.071481E-12   5.341674E+02   2.925109E+03   0.0           -2.182787E-11  -2.728484E-12
        97                  *TOTALS*      -4.038968E-28   7.958079E-13   0.0            0.0           -2.182787E-11  -2.728484E-12
0       98                  APP-LOAD       2.071481E-12   7.099428E+01  -2.057735E+03   0.0            0.0            0.0
        98           101    BAR            2.071481E-12  -5.341674E+02  -2.925109E+03   0.0           -2.925109E+04   5.341674E+03
        98           102    BAR           -4.142962E-12   4.631731E+02   4.982844E+03   0.0            2.925109E+04  -5.341674E+03
        98                  *TOTALS*       1.615587E-27  -1.932676E-12  -1.637090E-11   0.0            1.018634E-10  -3.637979E-12
0       99                  APP-LOAD       2.071481E-12   5.374116E+01  -2.293706E+03   0.0            0.0            0.0
        99           103    BAR            2.578120E-09  -4.590568E+03   3.082257E+03  -6.017940E+02   4.106689E+04   1.502659E+04
        99           104    BAR           -2.580192E-09   4.536827E+03  -7.885513E+02   6.017940E+02  -4.106689E+04  -1.502659E+04
        99                  *TOTALS*      -4.135903E-25  -2.728484E-12  -2.864908E-11  -1.034550E-11  -1.891749E-10  -1.509761E-10
0      100                  APP-LOAD       2.071481E-12   3.034552E+02  -2.594927E+03   0.0            0.0            0.0
       100           103    BAR           -2.578120E-09   4.590568E+03  -3.082257E+03   6.017940E+02  -7.188946E+04  -6.093227E+04
       100           110    BAR            3.841706E-09  -3.223407E+03   3.126311E+03   4.044459E+04   4.015574E+04   3.511926E+04
       100           210    BAR           -1.396984E-09  -2.123133E+03   2.650874E+03  -3.878379E+04   3.149504E+04   2.257834E+04
       100           310    BAR            1.891749E-10   4.525177E+02  -1.000000E+02  -2.262588E+03   2.386750E+02   3.234671E+03
       100                  *TOTALS*       5.784790E-11   1.376065E-09   5.875336E-10   1.382432E-10  -4.183676E-10  -1.717126E-09
0      110                  F-OF-MPC       6.904937E-13   4.305411E-24  -4.205951E+02   0.0            5.255696E+03   2.894283E-24
       110           110    BAR           -3.841706E-09   3.223407E+03  -3.126311E+03  -2.481303E+04  -3.113087E+04  -2.581409E+04

                                      G R I D   P O I N T   F O R C E   B A L A N C E

   POINT-ID    ELEMENT-ID     SOURCE             T1             T2             T3             R1             R2             R3
       110           115    BAR            4.132744E-09  -3.223407E+03   3.546906E+03   2.481303E+04   2.587517E+04   2.581409E+04
       110                  *TOTALS*       2.917288E-10  -2.037268E-10   1.491571E-10   0.0           -2.182787E-11  -2.328306E-09
0      111                  APP-LOAD       4.142962E-13   1.573849E-24   8.408417E+02   0.0            0.0            0.0
       111                  F-OF-MPC      -4.142962E-13  -1.573849E-24  -8.408417E+02   0.0            0.0            0.0
       111                  *TOTALS*       0.0            0.0            0.0            0.0            0.0            0.0
0      112                  APP-LOAD       2.761975E-13   2.731562E-24  -1.261437E+03   0.0            0.0            0.0
       112                  F-OF-MPC      -2.761975E-13  -2.731562E-24   1.261437E+03   0.0            0.0            0.0
       112                  *TOTALS*       0.0            0.0            0.0            0.0            0.0            0.0
0      115                  APP-LOAD       0.0           -1.043287E+02   1.497595E+03   0.0            0.0            0.0
       115           115    BAR           -4.132744E-09   3.223407E+03  -3.546906E+03  -7.078503E+03  -1.563614E+04  -1.650892E+04
       115           120    BAR            1.222361E-09  -6.093499E+02   2.046749E+03   1.084310E+04   1.558470E+04   3.794290E+03
       115           151    BAR            1.164153E-09  -2.509729E+03   2.561611E+00  -3.764593E+03   5.144116E+01   1.271463E+04
       115                  *TOTALS*      -1.746230E-09   2.441084E-09  -9.231371E-09   3.215973E-09   5.820766E-11  -2.095476E-09
0      120                  F-OF-MPC      -4.868232E-12  -6.093499E+02   2.046749E+03   0.0            9.676245E+03   2.035249E+03
       120           120    BAR           -1.280569E-09   6.093499E+02  -2.046749E+03  -7.275958E-10  -9.676245E+03  -2.035249E+03
       120                  *TOTALS*      -1.285437E-09   4.466756E-10   3.772129E-10  -7.275958E-10   8.185452E-11  -2.441539E-09
0      121                  APP-LOAD      -2.920939E-12  -7.117247E+02   2.958624E+03   0.0            0.0            0.0
       121                  F-OF-MPC       2.920939E-12   7.117247E+02  -2.958624E+03   0.0            0.0            0.0
       121                  *TOTALS*       0.0            0.0            0.0            0.0            0.0            0.0
0      122                  APP-LOAD      -1.947293E-12   1.023749E+02  -9.118744E+02   0.0            0.0            0.0
       122                  F-OF-MPC       1.947293E-12  -1.023749E+02   9.118744E+02   0.0            0.0            0.0
       122                  *TOTALS*       0.0            0.0            0.0            0.0            0.0            0.0
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0       150                 APP-LOAD    0.0           -2.542926E+03  1.028823E+01  0.0           0.0           0.0
        150          150    BAR         0.0            2.542926E+03 -1.028823E+01  0.0          -1.746230E-10  9.313226E-10
        150                 *TOTALS*    0.0            4.811227E-10  1.256204E-10  0.0          -1.746230E-10  9.313226E-10
0       151                 APP-LOAD    0.0            3.319735E+01 -7.726621E+00  0.0           0.0           0.0
        151          150    BAR         0.0           -2.542926E+03  1.028823E+01  0.0           5.144116E+01  1.271463E+04
        151          151    BAR        -1.164153E-09   2.509729E+03 -2.561611E+00  2.793968E-09 -5.144116E+01 -1.271463E+04
        151                 *TOTALS*   -1.164153E-09  -3.050445E-09  1.105233E-08  2.793968E-09  6.984919E-10  6.984919E-10
0       210                 F-OF-MPC    6.904937E-13   4.339081E-24 -2.105375E+02  0.0           5.757849E+03  2.778820E-24
        210          210    BAR         1.396984E-09   2.123133E+03 -2.650874E+03  2.552942E+04 -2.384264E+04 -1.644938E+04
        210          215    BAR        -2.328306E-09  -2.123133E+03  2.861411E+03 -2.552942E+04  1.808479E+04  1.644938E+04
        210                 *TOTALS*   -9.306321E-10  -1.979060E-09  5.775291E-11  0.0          -1.455192E-11 -2.561137E-09
0       211                 APP-LOAD    4.142962E-13   1.613777E-24  1.046301E+03  0.0           0.0           0.0
        211                 F-OF-MPC   -4.142962E-13  -1.613777E-24 -1.046301E+03  0.0           0.0           0.0
        211                 *TOTALS*    0.0            0.0           0.0           0.0           0.0           0.0
0       212                 APP-LOAD    2.761975E-13   2.725305E-24 -1.256838E+03  0.0           0.0           0.0
        212                 F-OF-MPC   -2.761975E-13  -2.725305E-24  1.256838E+03  0.0           0.0           0.0
        212                 *TOTALS*    0.0            0.0           0.0           0.0           0.0           0.0
                                          G R I D   P O I N T   F O R C E   B A L A N C E

   POINT-ID    ELEMENT-ID    SOURCE         T1             T2             T3             R1             R2             R3
0       215                 APP-LOAD    0.0           -5.477095E+00  1.485256E+03  0.0           0.0           0.0
        215          215    BAR         2.328306E-09   2.123133E+03 -2.861411E+03  1.122237E+04 -9.824609E+03 -1.032043E+04
        215          220    BAR         0.0            4.743958E+02  1.371979E+03 -7.334291E+03  9.760390E+03 -2.629428E+03
        215          251    BAR         5.355105E-09  -2.592052E+03  4.175926E+00 -3.888078E+03  6.421872E+01  1.294986E+04
        215                 *TOTALS*    7.683411E-09   1.895523E-08 -1.502485E-09  1.463923E-08 -3.958121E-09 -1.455192E-10
0       220                 F-OF-MPC    1.174961E-12   4.743958E+02  1.371979E+03  0.0           5.799829E+03 -1.259966E+03
        220          220    BAR        -5.820766E-11  -4.743958E+02 -1.371979E+03 -5.820766E-11 -5.799829E+03  1.259966E+03
        220                 *TOTALS*   -5.703270E-11  -5.238689E-10  1.366516E-10 -5.820766E-11 -2.437446E-10 -1.094577E-09
0       221                 APP-LOAD    7.049766E-13   4.891911E+02  1.845955E+03  0.0           0.0           0.0
        221                 F-OF-MPC   -7.049766E-13  -4.891911E+02 -1.845955E+03  0.0           0.0           0.0
        221                 *TOTALS*    0.0            0.0           0.0           0.0           0.0           0.0
0       222                 APP-LOAD    4.699844E-13  -1.479525E+01 -4.739763E+02  0.0           0.0           0.0
        222                 F-OF-MPC   -4.699844E-13   1.479525E+01  4.739763E+02  0.0           0.0           0.0
        222                 *TOTALS*    0.0            0.0           0.0           0.0           0.0           0.0
0       250                 APP-LOAD    0.0           -2.589971E+03  1.284374E+01  0.0           0.0           0.0
        250          250    BAR         0.0            2.589971E+03 -1.284374E+01  0.0           4.947651E-10  1.862645E-09
        250                 *TOTALS*    0.0            3.192326E-10 -1.686384E-10  0.0           4.947651E-10  1.862645E-09
0       251                 APP-LOAD    0.0           -2.080800E+00 -8.667818E+00  0.0           0.0           0.0
        251          250    BAR         0.0           -2.589971E+03  1.284374E+01  0.0           6.421872E+01  1.294986E+04
        251          251    BAR        -5.355105E-09   2.592052E+03 -4.175926E+00  6.519258E-09 -6.421872E+01 -1.294986E+04
        251                 *TOTALS*   -5.355105E-09  -1.561784E-08  3.349403E-09  6.519258E-09 -2.852175E-09  1.542503E-09
0       310                 F-OF-MPC   -6.139359E-12   4.525177E+02 -1.000000E+02  0.0          -5.000000E+01  1.928366E+03
        310          310    BAR        -1.891749E-10  -4.525177E+02  1.000000E+02 -2.328306E-10  5.000000E+01 -1.928366E+03
        310                 *TOTALS*   -1.953143E-10  -1.248281E-10 -2.273737E-13 -2.328306E-10 -5.479706E-11  2.085017E-10
0       311                 APP-LOAD   -3.683615E-12  -1.594143E+02 -6.000000E+01  0.0           0.0           0.0
        311                 F-OF-MPC    3.683615E-12   1.594143E+02  6.000000E+01  0.0           0.0           0.0
        311                 *TOTALS*    0.0            0.0           0.0           0.0           0.0           0.0
0       312                 APP-LOAD   -2.455744E-12   6.119320E+02 -4.000000E+01  0.0           0.0           0.0
        312                 F-OF-MPC    2.455744E-12  -6.119320E+02  4.000000E+01  0.0           0.0           0.0
        312                 *TOTALS*    0.0            0.0           0.0           0.0           0.0           0.0
0       881                 APP-LOAD    1.380987E-14   7.145248E-30 -2.000000E+01  0.0           0.0           0.0
        881                 F-OF-MPC   -1.380987E-14  -7.145248E-30  2.000000E+01  0.0           0.0           0.0
        881                 *TOTALS*    0.0            0.0           0.0           0.0           0.0           0.0
0       882                 APP-LOAD    2.761975E-14  -1.429050E-29 -4.000000E+01  0.0           0.0           0.0
        882                 F-OF-MPC   -2.761975E-14   1.429050E-29  4.000000E+01  0.0           0.0           0.0
        882                 *TOTALS*    0.0            0.0           0.0           0.0           0.0           0.0
0       890                 F-OF-MPC    8.285924E-14  -8.691779E-30  2.009004E+03 -2.990764E+03  8.029365E+03  1.242889E-13
        890           90    BAR        -8.285924E-14   8.691779E-30 -2.009004E+03  2.990764E+03 -8.029365E+03 -1.242889E-13
                                          G R I D   P O I N T   F O R C E   B A L A N C E

   POINT-ID    ELEMENT-ID    SOURCE         T1             T2             T3             R1             R2             R3
        890                 *TOTALS*    1.893266E-28   0.0           5.456968E-12  8.640200E-12 -1.818989E-12 -2.524355E-29
0       891                 APP-LOAD    1.380987E-14   1.546530E-30 -2.000000E+01  0.0           0.0           0.0
        891                 F-OF-MPC   -1.380987E-14  -1.546530E-30  2.000000E+01  0.0           0.0           0.0
        891                 *TOTALS*    0.0            0.0           0.0           0.0           0.0           0.0
0       892                 APP-LOAD    2.761975E-14  -3.093061E-30 -4.000000E+01  0.0           0.0           0.0
        892                 F-OF-MPC   -2.761975E-14   3.093061E-30  4.000000E+01  0.0           0.0           0.0
        892                 *TOTALS*    0.0            0.0           0.0           0.0           0.0           0.0
0       910                 F-OF-MPC    8.285924E-14   8.691779E-30  2.185288E+03  3.239990E+03  9.011810E+03 -1.242889E-13
        910           91    BAR        -8.285924E-14  -8.691779E-30 -2.185288E+03 -3.239990E+03 -9.011810E+03  1.242889E-13
        910                 *TOTALS*    1.388395E-28  -1.401298E-45 -7.275958E-12 -1.546141E-11  3.637979E-12 -7.573065E-29
0       911                 APP-LOAD    1.380987E-14  -1.546530E-30 -2.000000E+01  0.0           0.0           0.0
        911                 F-OF-MPC   -1.380987E-14   1.546530E-30  2.000000E+01  0.0           0.0           0.0
        911                 *TOTALS*    0.0            0.0           0.0           0.0           0.0           0.0
0       912                 APP-LOAD    2.761975E-14   3.093061E-30 -4.000000E+01  0.0           0.0           0.0
        912                 F-OF-MPC   -2.761975E-14  -3.093061E-30  4.000000E+01  0.0           0.0           0.0
        912                 *TOTALS*    0.0            0.0           0.0           0.0           0.0           0.0
0       921                 APP-LOAD    1.380987E-14  -7.145248E-30 -2.000000E+01  0.0           0.0           0.0
        921                 F-OF-MPC   -1.380987E-14   7.145248E-30  2.000000E+01  0.0           0.0           0.0
        921                 *TOTALS*    0.0            0.0           0.0           0.0           0.0           0.0
0       922                 APP-LOAD    2.761975E-14   1.429050E-29 -4.000000E+01  0.0           0.0           0.0
        922                 F-OF-MPC   -2.761975E-14  -1.429050E-29  4.000000E+01  0.0           0.0           0.0
        922                 *TOTALS*    0.0            0.0           0.0           0.0           0.0           0.0
```

```
                  * * * *  D B D I C T   P R I N T  * * * *      SUBDMAP = PRTSUM  ,  DMAP STATEMENT NO.     71

0                                   * * * *  A N A L Y S I S  S U M M A R Y  T A B L E  * * * *
0 SEID  PEID PROJ VERS APRCH      SEMG SEMR SEKR SELG SELR MODES DYNRED SOLLIN SOLNL LOOPID DESIGN CYCLE SENSITIVITY
 --------------------------------------------------------------------------------------------------------------------------
     0     0    1    1 '        '    T    T    T    T    T     F      F      T      0     F     -1            0           F
0SEID = SUPERELEMENT ID.
PEID = PRIMARY SUPERELEMENT ID OF IMAGE SUPERELEMENT.
 PROJ = PROJECT ID NUMBER.
 VERS = VERSION ID.
 APRCH = BLANK FOR STRUCTURAL ANALYSIS.  HEAT FOR HEAT TRANSFER ANALYSIS.
 SEMG = STIFFNESS AND MASS MATRIX GENERATION STEP.
 SEMR = MASS MATRIX REDUCTION STEP (INCLUDES EIGENVALUE SOLUTION FOR MODES).
 SEKR = STIFFNESS MATRIX REDUCTION STEP.
 SELG = LOAD MATRIX GENERATION STEP.
 SELR = LOAD MATRIX REDUCTION STEP.
 MODES = T (TRUE) IF NORMAL MODES OR BUCKLING MODES CALCULATED.
 DYNRED = T (TRUE) MEANS GENERALIZED DYNAMIC AND/OR COMPONENT MODE REDUCTION PERFORMED.
 SOLLIN = T (TRUE) IF LINEAR SOLUTION EXISTS IN DATABASE.
 LOOPID = THE LAST LOOPID VALUE USED IN THE NONLINEAR ANALYSIS.  USEFUL FOR RESTARTS.
 SOLNL = T (TRUE) IF NONLINEAR SOLUTION EXISTS IN DATABASE.
 DESIGN CYCLE = THE LAST DESIGN CYCLE (ONLY VALID IN OPTIMIZATION).
 SENSITIVITY = SENSITIVITY MATRIX GENERATION FLAG.

 No PARAM values were set in the Control File.

1                                    * * * END OF JOB * * *


 No Symbolic Replacement variables or values were specified.
```

Listing 7-33 Loads Output for Use of AEPARM in Example OSPREY.DAT

```
$...............................................................................
$
$ TRIM CASE: 1
$ RIGID INERTIAL LOADS
$
FORCE          1      97       0   1.0   2.07-12   0.0  -3000.
FORCE          1      98       0   1.0   2.07-12   0.0  -3000.
FORCE          1      99       0   1.0   2.07-12 2.80-24-3000.
FORCE          1     100       0   1.0   2.07-12 2.14-23-3000.
FORCE          1     111       0   1.0   4.14-13 1.57-24-600.
FORCE          1     112       0   1.0   2.76-13 2.73-24-400.
FORCE          1     121       0   1.0  -2.92-12 2.09-13-600.
FORCE          1     122       0   1.0  -1.95-12 1.86-13-400.
FORCE          1     211       0   1.0   4.14-13 1.61-24-600.
FORCE          1     212       0   1.0   2.76-13 2.73-24-400.
FORCE          1     221       0   1.0   7.05-13 2.06-11-600.
FORCE          1     222       0   1.0   4.70-13 1.37-11-400.
FORCE          1     311       0   1.0  -3.68-12 3.69-12-60.
FORCE          1     312       0   1.0  -2.46-12 2.46-12-40.
FORCE          1     881       0   1.0   1.38-14 7.15-30-20.
FORCE          1     882       0   1.0   2.76-14-1.43-29-40.
FORCE          1     891       0   1.0   1.38-14 1.55-30-20.
FORCE          1     892       0   1.0   2.76-14-3.09-30-40.
FORCE          1     911       0   1.0   1.38-14-1.55-30-20.
FORCE          1     912       0   1.0   2.76-14 3.09-30-40.
FORCE          1     921       0   1.0   1.38-14-7.15-30-20.
FORCE          1     922       0   1.0   2.76-14 1.43-29-40.
$...............................................................................


$
$ TRIM CASE: 1
$ ELASTIC AERODYNAMIC LOADS
$
FORCE          2      88       0   1.0     0.0     0.0   1104.63
FORCE          2      89       0   1.0     0.0     0.0   1024.38
FORCE          2      90       0   1.0     0.0   5000.     0.0
FORCE          2      91       0   1.0     0.0     0.0   1114.56
FORCE          2      92       0   1.0     0.0     0.0   1190.73
FORCE          2      97       0   1.0     0.0  -534.167 74.8909
FORCE          2      98       0   1.0     0.0   70.9943 942.265
FORCE          2      99       0   1.0     0.0   53.7412 706.294
FORCE          2     100       0   1.0     0.0   303.455 405.073
FORCE          2     111       0   1.0     0.0     0.0   1440.84
FORCE          2     112       0   1.0     0.0     0.0  -861.437
FORCE          2     115       0   1.0     0.0  -104.329 1497.6
FORCE          2     121       0   1.0     0.0  -711.725 3558.62
FORCE          2     122       0   1.0     0.0   102.375-511.874
```

```
FORCE          2     150       0   1.0     0.0   -2542.93 10.2882
FORCE          2     151       0   1.0     0.0    33.1974-7.72662
FORCE          2     211       0   1.0     0.0       0.0   1646.3
FORCE          2     212       0   1.0     0.0       0.0  -856.839
FORCE          2     215       0   1.0     0.0   -5.4771   1485.26
FORCE          2     221       0   1.0     0.0    489.191 2445.96
FORCE          2     222       0   1.0     0.0   -14.7953-73.9763
FORCE          2     250       0   1.0     0.0   -2589.97 12.8437
FORCE          2     251       0   1.0     0.0   -2.0808 -8.66782
FORCE          2     311       0   1.0     0.0   -159.414   0.0
FORCE          2     312       0   1.0     0.0    611.932   0.0
MOMENT         2      88       0   1.0   755.254 3940.96    0.0
MOMENT         2      89       0   1.0  -612.144 3988.41    0.0
MOMENT         2      91       0   1.0   661.998 4510.1     0.0
MOMENT         2      92       0   1.0  -814.183 4401.71    0.0
$..............................................................................
$


$ TRIM CASE: 1
$ ELASTIC (AERODYNAMIC + APPLIED - INERTIAL) LOADS
$
FORCE          3      88       0   1.0     0.0       0.0   1104.63
FORCE          3      89       0   1.0     0.0       0.0   1024.38
FORCE          3      90       0   1.0     0.0     5000.      0.0
FORCE          3      91       0   1.0     0.0       0.0   1114.56
FORCE          3      92       0   1.0     0.0       0.0   1190.73
FORCE          3      97       0   1.0   2.07-12-534.167-2925.11
FORCE          3      98       0   1.0   2.07-12 70.9943-2057.74
FORCE          3      99       0   1.0   2.07-12 53.7412-2293.71
FORCE          3     100       0   1.0   2.07-12 303.455-2594.93
FORCE          3     111       0   1.0   4.14-13 1.57-24 840.842
FORCE          3     112       0   1.0   2.76-13 2.73-24-1261.44
FORCE          3     115       0   1.0     0.0   -104.329 1497.6
FORCE          3     121       0   1.0  -2.92-12-711.725 2958.62
FORCE          3     122       0   1.0  -1.95-12 102.375-911.874
FORCE          3     150       0   1.0     0.0   -2542.93 10.2882
FORCE          3     151       0   1.0     0.0    33.1974-7.72662
FORCE          3     211       0   1.0   4.14-13 1.61-24 1046.3
FORCE          3     212       0   1.0   2.76-13 2.73-24-1256.84
FORCE          3     215       0   1.0     0.0   -5.4771   1485.26
FORCE          3     221       0   1.0   7.05-13 489.191 1845.96
FORCE          3     222       0   1.0   4.70-13-14.7953-473.976
FORCE          3     250       0   1.0     0.0   -2589.97 12.8437
FORCE          3     251       0   1.0     0.0   -2.0808 -8.66782
FORCE          3     311       0   1.0  -3.68-12-159.414-60.
FORCE          3     312       0   1.0  -2.46-12 611.932-40.
FORCE          3     881       0   1.0   1.38-14 7.15-30-20.
FORCE          3     882       0   1.0   2.76-14-1.43-29-40.
FORCE          3     891       0   1.0   1.38-14 1.55-30-20.
FORCE          3     892       0   1.0   2.76-14-3.09-30-40.
FORCE          3     911       0   1.0   1.38-14-1.55-30-20.
FORCE          3     912       0   1.0   2.76-14 3.09-30-40.
FORCE          3     921       0   1.0   1.38-14-7.15-30-20.
FORCE          3     922       0   1.0   2.76-14 1.43-29-40.
MOMENT         3      88       0   1.0   755.254 3940.96    0.0
MOMENT         3      89       0   1.0  -612.144 3988.41    0.0
MOMENT         3      91       0   1.0   661.998 4510.1     0.0
MOMENT         3      92       0   1.0  -814.183 4401.71    0.0
```

8 Flutter Analysis Problems

Overview

The examples in this chapter illustrate a range of unsteady aerodynamic problems, primarily flutter analyses, using the three flutter methods and six aerodynamic methods available in MSC Nastran. Estimation of aerodynamic static and dynamic stability derivatives and interactions with control systems and thermal loading are also demonstrated.

Thirteen examples (or example pairs) are presented:

Examples	Descriptions
HA145A	**Three Degree of Freedom Airfoil and Fuselage.** It presents a two-dimensional airfoil mounted on a fuselage with a plunging degree of freedom. This example illustrates the characteristics of the PK-method of flutter analysis for predicting both flutter and divergence of an unrestrained vehicle.
Flutter analyses of the cantilevered BAH wing	
HA145B	**Flutter Analysis of Jet Transport Wing by Lifting Surface Theory**
HA145C	**Flutter and Divergence Analysis of Jet Transport Wing by Strip Theory** illustrate the PK- and K-methods for finding flutter and divergence speeds and also show significant differences in results between the Doublet-Lattice method (DLM) and Strip Theory.
HA145D	**Flutter Analysis of Jet Transport Wing/Aileron by Strip Theory** It includes the aileron using Strip Theory with an approximation to the circulation function and experimental correction factors for the spanwise loading.
Dmonstating effects of Mach number and demonstrate experimental correlation with wind-tunnel tests of a series of 15-deg swept-wing models	
HA145E	It uses the KE-flutter method with DLM aerodynamics at a Mach number of $m = 0.45$.
HA145F	It uses the PK-method with supersonic Mach Box aerodynamics at $m = 1.3$.
HA145FA	reconsider Example HA145F using ZONA51 aerodynamics.
HA145FB	
HA145G	Uses the PK-method with the high supersonic Piston Theory aerodynamics at $m = 3.0$.
The remaining examples present a variety of problems:	
HA145HA	perform supersonic panel flutter analyses of a square plate using Piston Theory and ZONA51 aerodynamics.
HA145HB	
HA145I	demonstrates the calculation of aerodynamic static and dynamic stability derivatives. Example HA145I applies the DLM to the forward-swept-wing (FSW) airplane to obtain aerodynamic coefficients for lateral-directional motions.

Examples	Descriptions
HA110A HA145J	Illustrates the inclusion of a control system in two different stability analyses. These examples consider a simplified air-to-air missile, first without and then with the effects of an airstream, in representative servoelastic and aeroservoelastic stability analyses.
HA153A HA145KR	Presents an aerothermoelastic analysis of a rectangular wing constructed and heated in a manner to emphasize thermoelastic effects on the aeroelastic characteristics. The solution requires sequential analyses of the nonlinear effects of temperature on the stiffness matrix and restarts in the aeroelastic analyses. Only the flutter analysis is demonstrated. However, the requirements for restarts for static and dynamic aeroelastic analyses are also discussed.

Three Degree of Freedom Airfoil and Fuselage (Example HA145A)

Rodden and Bellinger (1982a) [Reference 44] studied atwo degree of freedom (2 DOF) airfoil to illustrate the characteristics of the PK-flutter method. Later, a *fuselage* DOF in plunge was added to the problem by them (1982b) to investigate the effects of a rigid body motion. The 3 DOF case is considered here.

The airfoil is connected to the fuselage mass by bending and torsion springs, and the fuselage is free to plunge, as shown in Figure 8-1. The airfoil center of gravity may be at either 37% or 45% chord; its aerodynamic center is at 25% chord, and the springs are connected to the “elastic axis” at 40% chord. The remaining parameters for the analysis at sea level include a chord of 6.0 ft, a radius of gyration of 1.5 ft about the elastic axis, a mass ratio $\mu = 20.0$, uncoupled bending and torsion frequencies of 10.0 and 25.0 rad/sec, respectively, and equal structural damping coefficients $g = 0.03$ in both modes.

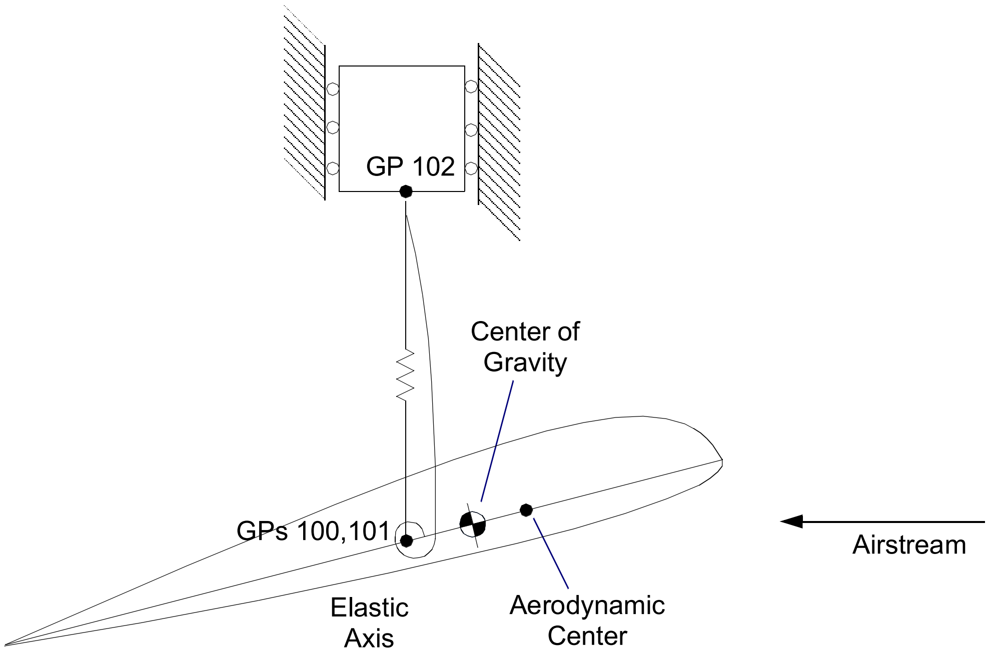

Figure 8-1 Three Degree of Freedom Airfoil and Fuselage

The airfoil lift curve slope is the theoretical two-dimensional incompressible value of:

$$C_{l_a} = 2\pi / \mathrm{rad} \quad .$$

Both the exact Theodorsen function and an approximation are used for the circulation function. The approximation constants are those of W. P. Jones (1945):

$b_0 = 1.0$, $b_1 = 0.165$, $b_2 = 0.335$, $\beta_1 = 0.041$, and $\beta_2 = 0.320$.

The mass ratio and the foregoing parameters translate to the following dimensional input parameters:

Airfoil Mass = Fuselage Mass	1.3447 slugs
Static Unbalance about Elastic Axis	+0.24205 slug-ft for 37% c.g. -0.40342 slug-ft for 45% c.g.
Moment of Intertia about Elastic Axis	3.0256 slug-ft^2
Bending Stiffness	134.47 lb/ft
Torsion Stiffness	1891.0 ft-lb/rad

Bending Damping	0.40341 lb-sec/ft
Torsion Damping	2.2692 ft-lb-sec/rad

The input data are set up with options for both centers of gravity and both aerodynamic representations. The option selected is the 37% chord center of gravity with the approximate Theodorsen function with the remaining options commented out using a $ in the first column of the data entry.

Bulk Data Entries

The Bulk Data entries specify that the two-dimensional airfoil has unit width. GRID 100 is on the airfoil centerline at the elastic axis with freedoms in plunge (T3) and pitch (R2). GRID 101 defines the elastic axis at the outboard edge of the strip and is connected to GRID 100 by RBAR 101. GRID 102 is the fuselage with only the plunge degree of freedom.

- CELAS2 103 is the bending spring connecting the airfoil elastic axis to the fuselage.
- CELAS2 105 is the torsion spring between the airfoil elastic axis and ground (since the fuselage does not pitch).
- CMASS2 111 is the fuselage concentrated mass
- CONM1 110 gives the mass coupling of the airfoil
- CDAMP2 123 is the bending damper between the airfoil and the fuselage
- CDAMP2 125 is the torsion damper to ground. ElGR selects the Modified Givens method MGlV for analysis of the vibration eigenvalues and eigenvectors.

This completes the structural data. Next, the aerodynamic data are considered.

- `AERO`: The `AERO` entry includes a velocity of 100.0 fps (this is not needed for a flutter analysis but is required for a response analysis), the reference chord, sea-level density, and no symmetry or ground effect.
- `CAERO4`: The `CAERO4` entry specifies Strip Theory for one strip with its leading edge 2.4 ft upstream from the elastic axis, a 6.0 ft chord and a unit width.
- `PAERO4`: Two `PAERO4` entries are shown: one for the exact Theodorsen function and the other for the optional approximate circulation function. `PAERO4` leads to the exact function by taking `CLA = LCLA = CIRC = LClRC = 0`, the absence of a control surface is indicated by `DOC1 = CAOC1 = GAPO1 = 0.0`, and no `AEFACT` entry is required.
- `PAERO4`: It is an optional entry. It specifies the lift curve slope of 2π via `CLA = LCLA = 0`, a two-term approximation via `ClRC = 2` with the W. P. Jones coefficients on AEFACT 13 for Mach number, $m = 0.0$. This approximation to the circulation function is (Fung, 1969, p. 215):

$$C(k) \approx 1 - \frac{0.165}{1 - i0.041/k} - \frac{0.335}{1 - i0.32/k} \tag{8-1}$$

A series of reduced frequencies for $m = 0.0$ is specified on two MKAERO1 entries from $k = 0.001$ to $k = 5.0$ in order to cover the frequency range of interest in the PK-flutter solution.

The linear spline SPLlNE2 provides the data for the connection between the aerodynamics and the structure, which consists simply of aerodynamic element CAERO4 1000 and SET1 of grid points 100 and 101. The spline is rigidly attached to the elastic axis by selecting DTHX = DTHY = 0.0.

FLFACT 1 gives the air density ratio and FLFACT 2 gives the Mach number. FLFACT 3 gives the series of velocities for flutter analysis by the PK-method; the negative values call for flutter modes (eigenvectors) as well as eigenvalues to be printed. The FLUTTER 3 entry specifies the British Flutter Method (PK). The FLUTTER 4 entry specifies the American Flutter Method (K), and FLFACT 4 provides the series of reduced frequencies required by the K-method. The ENDDATA entry ends the Bulk Data Section.

MPDPRM,HDF5,1 requests output to the NDRH5 data base while PARAM,OPPHIPA,1 requests output of the real eigenvectors, including the projection of these modes onto the aerodynamic mesh.

Case Control Commands

In the Case Control Section, the title and label are shown along with the other options.

- `ECHO = BOTH` requests that the annotated Bulk Data Section with all comment entries be printed as well as the sorted data entries.
- `METHOD = 1` specifies the eigenvalue method (ElGR entry) for the vibration analyses.
- `SVEC = ALL` requests the vibration modes printed for the degrees of freedom in the analysis set.
- `D1SP = ALL` requests the displacements at all grid points.

The multiple subcase capability of SOL 145 is illustrated by requesting analyses by two flutter methods.

- In Subcase 1, `FMETHOD = 3` specifies the PK-flutter method (FLUTTER entry)
- In Subcase 2, `FLUTTER = 4` specifies the K-method, and the complex eigenvalue method by `CMETHOD = 20` as required in the K-method.

The remaining data specify the plotting formats for the V-g and V-f curves. `BEGIN BULK` is placed at the end of the Case Control Section.

In the Executive Control Section, ID MSC, HA145A identifies this problem. TIME 5 restricts the run time to 5.0 CPU minutes. SOL 145 calls for the Aerodynamic Flutter DMAP Sequence, and CEND completes the Executive Control Section.

Output

Listing 8-1 shows the input deck while Listing 8-2 contains the sorted bulk data deck. Selected output follows in Listing 8-3. The plotted V-g and V-f curves for the PK-method are shown in Figure 8-2.

The printed output begins with the vibration analysis which gives all three natural frequencies, generalized masses and vibration modes of the undamped, unrestrained system. The rigid body frequency is a computed zero (using the `SUPORT` entry would result in an exact zero). Three real eigenvectors are printed.

The output from the first subcase is the PK-flutter analysis. Listing 8-3 presents a sampling of the actual output that is given in the .f06 file so as to limit the length of the listing. The first item is the "LESS CRITICAL REAL ROOTS" and the meaning of these roots is as follows:

Flutter analysis typically produces sets of complex conjugate pairs of roots and, by convention, only the results with a positive imaginary part are presented in the output. When real roots are extracted there is no longer a conjugate result so a decision has been to only present the “more critical” real root in the flutter summary; that is, the root that is farthest to the right on the real axis. Sometimes, particularly in the presence of a control system, the less critical roots are of importance and these are the roots that are provided at each analysis velocity. For the sake of brevity, the “LESS CRITICAL ROOTS” in Listing 8-3 are limited to the set of velocities for which eigenvectors are requested.

The flutter summaries are given for a series of POINTS which refer to a mode number and at the Mach number, density and velocities provided on the FLFACT entries.

A subset of the complex eigenvectors that were requested using negative velocities on the FLFACT entry is presented in Listing 8-3. Table 8-1 lists the eigenvalues that correspond to the complex eigenvectors that are listed in both modal and physical degrees of freedom in the listing.

Table 8-1 Eigenvalues for the Complex Eigenvectors shown in Listing 8-3 for the PK-flutter analysis

Velocity	Point	Eigenvalue
230	2	-.1183 + 7.437i
240	2	.4625 + 7.204i
280	3	-.0415 + 16.943i
290	3	.0731 + 16.865i

PK-Method Results

The unique characteristics of the PK-method should be noted. In the case of the constrained fuselage (which is obtained by adding the T3 constraint to GRID 102 in this example), Rodden and Bellinger (1982a) [Reference 44] showed that the PK-results were not continuous. A discontinuity occurs at some velocity (slightly different in the two representation of the Theodorsen function) at which the PK algorithm converges to an aerodynamic lag root (with zero frequency) rather than the bending root. The PK algorithm in MSC Nastran then skips over the bending root in the reduced frequency lining-up process and next obtains the torsion root. In the unrestrained case (the present example), Rodden and Bellinger (1982b) [Reference 45] did not find an obvious aerodynamic lag root because the PK solution appeared to be continuous, as is shown in Figure 8-2. The reason for the different behavior between restrained and unrestrained systems is a subject for further study. From Figure 8-2 and the printed Flutter Summary for Point 2, the “dynamic divergence” speed (that is, the speed at which the oscillatory instability finds its origin in a tendency to static divergence) and frequency are 232.0 ft/s and 1.177 Hz, respectively. From Figure 8-2 and the Flutter Summary for Point 3, the flutter speed and frequency are 283.1 ft/s and 2.692 Hz, respectively. These results are only slightly different from those obtained by the “transient solution” in Rodden and Bellinger (1982b) [Reference 45].

Some explanation of the damping in Point 1 of the PK-Flutter Summary is also in order. The unrestrained system, free to plunge, has a zero eigenvalue as can be shown exactly with frequency-independent aerodynamics (that is, with aerodynamic lags neglected). A frequency of zero is given for Point 1 in the Summary, but the damping is not zero. The damping should be regarded as a computed zero and should not be interpreted as an instability between 120 and 140 ft/s.

Main Index

K-Method Results

Listing 8-3 concludes with Flutter Summaries for Subcase 2, the K-method. The dynamic divergence speed and frequency are found by interpolating the second mode results to $g = 0$ between Points 6 and 7. The speed and frequency by linear interpolation are 231.9 ft/s and 1.196 Hz, respectively. The flutter speed and frequency are found by interpolating the third mode results between Points 2 and 3. The speed and frequency are 301.2 ft/s and 2.658 Hz, respectively. The interpolated results for the K-method differ slightly from the PK-method because of the wide spacing of the reduced frequencies in the K-method. A more refined K-method will lead to agreement with the PK-method.

The flutter eigenvectors presented at the end of the listing are a subset of those in the .f06 and, as in the PK-case, are selected around the instability points. Table 8-2 lists the eigenvalues that correspond to listed complex eigenvectors. The labeling of these eigenvectors as being No. 5 or No. 6 is an artifact of the complex eigenanalysis where six roots are extracted and the three relevant ones are determined based on the sign of the imaginary part or the most critical of the real roots.

Table 8-2 Eigenvalues for the complex eigenvectors shown in Listing 8-3 for the K-method flutter analysis

KFREQ	Root	Eigenvalue
0.18	3	-1.592 + 28.15i
0.16	3	0.902 + 31.13i
0.10	2	-2.622 + 230.3i
0.08	2	17.387 + 240.4i

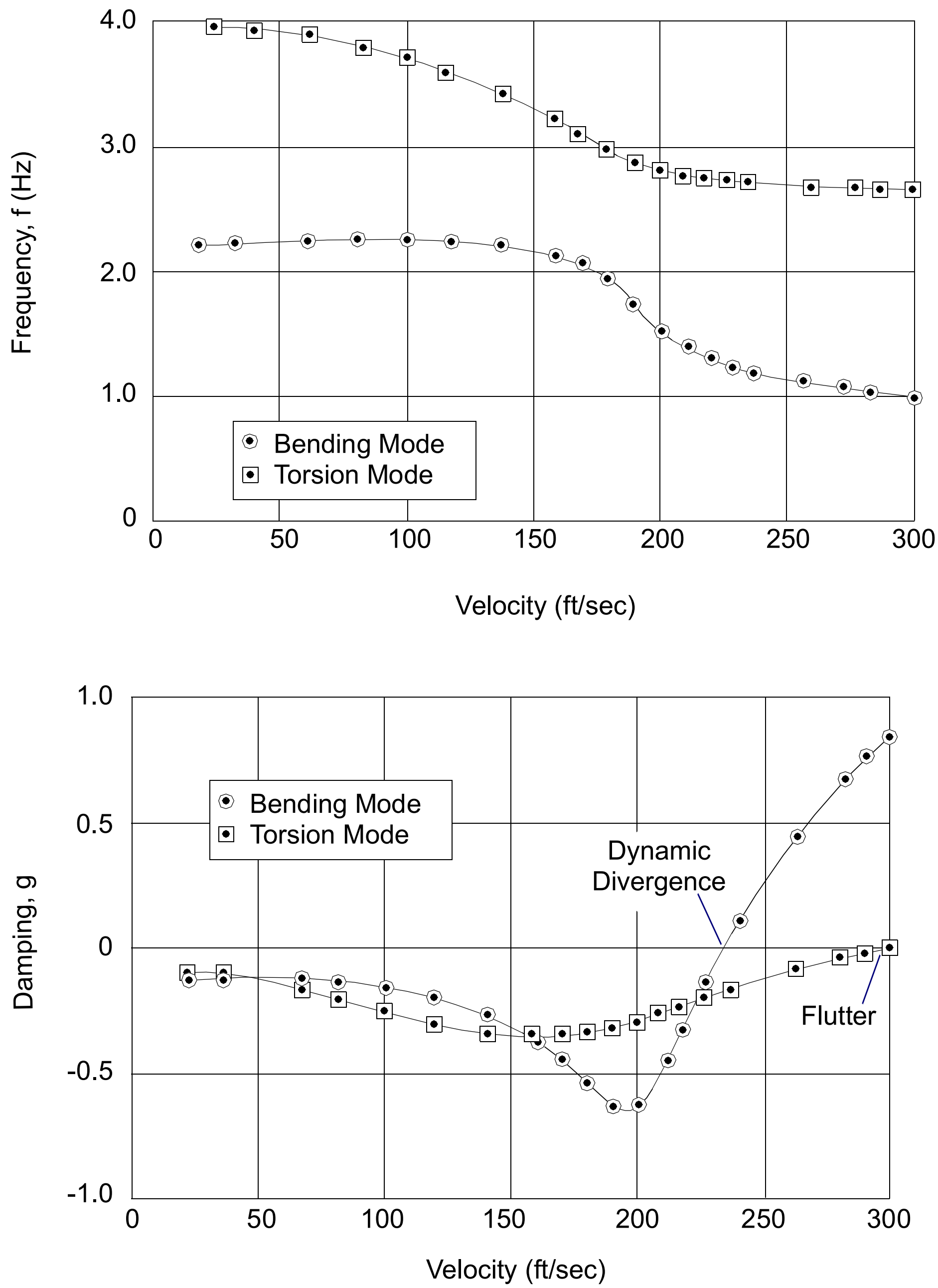

Figure 8-2 V-g and V-f Curves for Three Degree of Freedom Aeroelastic Model

Listing 8-1 Input Files for Three Degree of Freedom Airfoil and Fuselage

```
 $ID MSC, HA145A
$$$$$$$$    HANDBOOK FOR AEROELASTIC ANALYSIS EXAMPLE HA145A    $$$$$$$$
$                                                                      $
$       MODEL DESCRIPTION       A TWO-DIMENSIONAL AIRFOIL IDEALIZED    $
$                               AS A SINGLE STRIP WITH A UNIT WIDTH,   $
$                               A MASS AT MID-SPAN WITH FREEDOM TO     $
$                               MOVE VERTICALLY RELATIVE TO A DUMB-    $
$                               BELL AT MID-SPAN WITH A DISPLACEMENT   $
$                               SPRING BETWEEN THEM.  THE DUMBBELL     $
$                               IS ATTACHED BY A TORSION SPRING TO     $
$                               GROUND.  THIS RESULTS IN ONE RIGID     $
$                               BODY AND TWO FLEXIBLE DEGREES OF       $
$                               FREEDOM.  THIS EXAMPLE HAS BEEN        $
$                               PUBLISHED IN THE JOURNAL OF AIRCRAFT,  $
$                               SEPT. 1982, PP. 796-797.               $
$                                                                      $
$       SOLUTION                PK FLUTTER ANALYSIS METHOD USING       $
$                               STRIP THEORY AERODYNAMICS WITH THE     $
$                               W.P.JONES APPROXIMATION TO THE         $
$                               THEODORSEN CIRCULATION FUNCTION.       $
$                                                                      $
$       OUTPUT                  DISPLACEMENTS, AERODYNAMIC FORCES      $
$                               AND X-Y PLOTS OF V-G FLUTTER DATA      $
$                                                                      $
$$$$$$$                                                         $$$$$$$$

TIME  5 $ TIME IN CPU MINUTES
SOL  145 $ FLUTTER ANALYSIS
CEND
TITLE = EXAMPLE HA145A: THREE DEGREE OF FREEDOM AEROELASTIC MO HA145A
SUBTI = 2-D AERO, W.P. JONES C(K) WITH PK- AND K- FLUTTER METHODS
$SUBTI = 2-D AERO, EXACT C(K) WITH PK- AND K- FLUTTER METHODS
LABEL = ONE RIGID BODY AND TWO FLEXIBLE MODES, C.G. AT 0.37 CHORD
$LABEL = ONE RIGID BODY AND TWO FLEXIBLE MODES, C.G. AT 0.45 CHORD
  ECHO    = BOTH
  METHOD  = 1    $ MODIFIED GIVENS EIGENVALUE METHOD
  SVEC    = ALL  $ PRINT THE VIBRATION MODES
  DISP    = ALL  $ PRINT THE FLUTTER MODES
SUBCASE 1
  FMETHOD = 3    $ PK FLUTTER METHOD
SUBCASE 2
  FMETHOD = 4    $ K FLUTTER METHOD
  CMETHOD = 20
OUTPUT(XYOUT)
  CSCALE 2.0
  PLOTTER NASTRAN
  CURVELINESYMBOL = -6
  YTTITLE = DAMPING  G
  YBTITLE = FREQUENCY  F  Hz
  XTITLE  = VELOCITY  V (ft/sec)
  XTGRID LINES = YES
  XBGRID LINES = YES
  YTGRID LINES = YES
  YBGRID LINES = YES
  UPPER TICS  = -1
  TRIGHT TICS = -1
  BRIGHT TICS = -1
  XYPLOT VG / 1(G,F) 2(G,F) 3(G,F)
BEGIN BULK

mdlprmhdf51
parampost-1
paramopphipa1
paramogeomno
```

Listing 8-1 Input Files for Three Degree of Freedom Airfoil and Fuselage (Continued)

```
$*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
$                                                                        $
$        THE ANNOTATIONS IN THIS INPUT DECK ARE INTENDED TO              $
$        EXPLAIN THE DATA ON THE ENTRY IMAGES FOR THIS SPECIFIC          $
$        EXAMPLE WITHOUT REFERENCE TO THE VARIOUS MANUALS WHERE          $
$        MORE GENERAL DESCRIPTIONS WILL BE FOUND.                        $
$                                                                        $
$*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
$                                                                        $
$                        * * * STRUCTURAL DATA * * *                     $
$                                                                        $
$                             (LB-FT-SEC SYSTEM)                         $
$                                                                        $
$                           * * GRID GEOMETRY * *                        $
$                                                                        $
$        GRID  102      (T3)  SIMULATED FUSELAGE POINT                   $
$        GRID  100-101  (T3)  WING POINTS                                $
$                                                                        $
$        THE GRID ENTRY DEFINES THE LOCATION OF A STRUCTURAL GRID        $
$        POINT.  LISTED ARE ITS COORDINATE SYSTEM ID, ITS LOCATION,      $
$        THE ID OF THE COORDINATE SYSTEM IN WHICH ITS DISPLACEMENTS      $
$        ARE DEFINED, ITS PERMANENT SINGLE-POINT CONSTRAINTS AND         $
$        ITS ASSOCIATED SUPERELEMENT ID.                                 $
$                                                                        $
$       ID      CP      X1      X2      X3      CD      PS      SEID
GRID    100             0.      0.5     0.              1246
GRID    101             0.      1.0     0.
GRID    102             0.      0.5     0.              12456
$                                                                        $
$                   * * STRUCTURAL STIFFNESS PROPERTIES * *              $
$                                                                        $
$                       * SPRING MOUNTING DATA *                         $
$                                                                        $
$        THE CELAS2 ENTRY DEFINES A SCALAR SPRING ELEMENT WITHOUT        $
$        REFERENCE TO A PROPERTY ENTRY, IN THIS CASE K IS THE SPRING     $
$        CONSTANT, G1 AND G2 ARE JOINED BY THE SPRING (DEFAULT IS        $
$        TO GROUND), C1 AND C2 ARE THE DOFS AT THESE POINTS, GE IS       $
$        THE DAMPING COEFFICIENT AND S IS THE STRESS COEFFICIENT.        $
$        POINT 102 MOVES RELATIVE TO POINT 100 LIKE A PISTON MOVES       $
$        IN A CYLINDER.                                                  $
$                                                                        $
$       EID     K       G1      C1      G2      C2      GE      S
CELAS2  103     134.47  100     3       102     3
CELAS2  105     1891.   100     5
$                                                                        $
$        THE RBAR ENTRY DEFINES A RIGID BAR.  LISTED ARE THE GRID        $
$        POINTS AT EACH END AND THE DEPENDENT AND INDEPENDENT DOFS       $
$        AT EACH END.  THE NUMBER OF INDEPENDENT DOFS AT THE TWO         $
$        ENDS MUST EQUAL SIX.  BY DEFAULT THOSE NOT DECLARED INDE-       $
$        PENDENT ARE MADE DEPENDENT.                                     $
$                                                                        $
$       EID     GA      GB      CNA     CNB     CMA     CMB
RBAR    101     100     101     123456
$                                                                        $
$                    * * MASS AND INERTIA PROPERTIES * *                 $
$                                                                        $
$        THE CMASS2 ENTRY DEFINES A SCALAR MASS ELEMENT WITHOUT          $
$        REFERENCE TO A PROPERTY ENTRY.  IT LISTS THE MASS, THE          $
$        GRID NO. AND ITS DOF COMPONENTS.  WHEN TWO GRID POINTS          $
$        ARE LISTED THE MASS IS ADDED TO BOTH POINTS.                    $
$                                                                        $
$                            * FUSELAGE MASS *                           $
$                                                                        $
$       EID     M       G1      C1      G2      C2
CMASS2  111     1.3447  102     3
```

Listing 8-1 Input Files for Three Degree of Freedom Airfoil and Fuselage (Continued)

```
$                                                                         $
$        THE CONM1 ENTRY DEFINES A 6 BY 6 SYMMETRIC INERTIA MATRIX        $
$        FOR A GRID POINT.  LISTED IS THE ID, THE GRID POINT NO.,         $
$        THE COORDINATE SYSTEM IN WHICH THE INERTIA MATRIX IS             $
$        DEFINED AND THE LOWER LEFT TRIANGULAR PART OF THE MATRIX.        $
$                                                                         $
$                            * WING MASS *                                $
$                                                                         $
$       EID     G       CID     M11     M21     M22     M31     M32
CONM1   110     100                                                     +CNM1
$ ELASTIC AXIS AT 37 PERCENT CHORD
$       M33     M41     M42     M43     M44     M51     M52     M53
+CNM1   1.3447                                                  0.24205 +CNM1A
$       M54     M55     M61     M62     M63     M64     M65     M66
+CNM1A          3.0256
$                                  * * *                                  $
$ ELASTIC AXIS AT 45 PERCENT CHORD
$       M33     M41     M42     M43     M44     M51     M52     M53
$+CNM1  1.3447                                                  -.40342 +CNM1A
$                                  * * *                                  $
$                                                                         $
$                                                                         $
$        THE CDAMP2 ENTRY DEFINES A SCALAR DAMPER ELEMENT WITHOUT REF-    $
$        ERENCE TO A PROPERTY ENTRY.  B IS THE DAMPER CONSTANT, G1 AND    $
$        G2 ARE THE GRID POINTS TO WHICH THE DAMPER IS ATTACHED AND       $
$        C1 AND C2 ARE THE DOF COMPONENTS IN WHICH THEY MOVE.             $
$                                                                         $
$       EID     B       G1      C1      G2      C2
CDAMP2  123     .40341  100     3       102     3
CDAMP2  125     2.2692  100     5
$                                                                         $
$                                                                         $
$                     * * * AERODYNAMIC DATA * * *                        $
$                                                                         $
$                          (LB-FT-SEC SYSTEM)                             $
$                                                                         $
$                       * * ELEMENT GEOMETRY * *                          $
$                                                                         $
$        THE AERO ENTRY SPECIFIES THE AERO COORDINATE SYSTEM, THE         $
$        REFERENCE LENGTHS PLUS SYMMETRY KEYS.  SYMXZ = 0 INDICATES       $
$        THAT THE MODEL IS MOUNTED WITH NO ROOT REFLECTION PLANE;         $
$        SYMXY = 0 INDICATES THAT THE MODEL IS MOUNTED FAR ENOUGH         $
$        FROM THE FLOOR SO THAT REFLECTION EFFECTS ARE NEGLIGIBLE.        $
$                                                                         $
$       ACSID   VELOCITY REFC   RHOREF  SYMXZ   SYMXY
AERO            100.    6.      .002378 0       0
$                                                                         $
$               * * SPLINE FIT ON THE LIFTING SURFACES * *                $
$                                                                         $
$                    * BEAM SPLINE FIT ON THE WING *                      $
$                                                                         $
$        THE SPLINE2 ENTRY SPECIFIES A BEAM SPLINE FOR INTERPOLAT-        $
$        ION OVER THE REGION OF THE CAERO ENTRY (ID1 AND ID2 ARE          $
$        THE FIRST AND LAST BOXES IN THIS REGION).  SETG REFERS           $
$        TO A SET1 ENTRY WHERE THE STRUCTURAL GRID POINTS ARE             $
$        DEFINED.  DZ AND DTOR ARE SMOOTHING CONSTANTS FOR LINEAR         $
$        ATTACHMENT AND TORSIONAL FLEXIBILITIES.  DTHX AND DTHY           $
$        ARE ROTATIONAL ATTACHMENT FLEXIBILITIES. CID IDENTIFIES          $
$        THE SPLINE COORDINATE SYSTEM AND ITS AXIS.                       $
$                                                                         $
```

Listing 8-1 Input Files for Three Degree of Freedom Airfoil and Fuselage (Continued)

```
$       EID     CAERO   ID1     ID2     SETG    DZ      DTOR    CID
SPLINE2 1201    1000    1000    1000    1100    0.      1.      0       +SP2
$       DTHX    DTHY
+SP2    0.      0.
$                                                                       $
$        THE SET1 ENTRY DEFINES THE SETS OF STRUCTURAL GRID POINTS      $
$        TO BE USED BY THE BEAM SPLINE FOR INTERPOLATION.               $
$                                                                       $
$       SID     G1      G2      G3      ETC
SET1    1100    100     101
$                                                                       $
$        THE CAERO4 ENTRY IS USED TO SPECIFY STRIP THEORY AERO.         $
$        PID IDENTIFIES A PAERO4 ENTRY WHERE THE ELEMENT PROPERTIES     $
$        ARE GIVEN, CP DEFAULTS TO THE BASIC COORDINATE SYSTEM,         $
$        NSPAN IS THE NUMBER OF EQUAL SPAN STRIPS (IF UNEQUAL,          $
$        LSPAN WOULD SPECIFY AN AEFACT ENTRY THAT WOULD DEFINE THE      $
$        STRIPS WIDTHS).  THE CONTINUATION ENTRY DEFINES THE INBD       $
$        AND OUTBD LEADING EDGE POINTS AND THE CHORDS.                  $
$                                                                       $
$       EID     PID     CP      NSPAN   LSPAN
CAERO4  1000    1000            1                                       +CA1
$       X1      Y1      Z1      X12     X4      Y4      Z4      X43
+CA1    -2.4    0.      0.      6.      -2.4    1.      0.      6.
$                                                                       $
$        THE PAERO4 ENTRY DEFINES PROPERTIES OF THE STRIP ELEMENTS      $
$        FOR STRIP THEORY AERODYNAMICS.  IT OFFERS A WIDE VARIETY       $
$        OF OPTIONS.  CLA DEFAULTS TO NO COMPRESSIBILITY CORRECTION     $
$        AND NO CORRECTIONS OF LIFT CURVE SLOPES.  LCLA MUST BE ZERO    $
$        WHEN CLA IS ZERO.  CIRC=0 SPECIFIES THE EXACT EXPRESSION FOR   $
$        THE THEODORSEN CIRCULATION FUNCTION.  DOC, CAOC AND GAPOC      $
$        ARE REQUIRED EVEN THOUGH THE STRIP HAS NO CONTROL SURFACE.     $
$        IN FRACTIONS OF CHORD THESE ARE THE DISTANCE FROM THE QUARTER  $
$        CHORD TO THE HINGE LINE, THE CONTROL SURFACE CHORD AND THE     $
$        GAP BETWEEN THE PRIMARY SURFACE AND THE CONTROL SURFACE.       $
$        CAOC1=0. SPECIFIES NO CONTROL SURFACE.                         $
$                                                                       $
$       PID     CLA     LCLA    CIRC    LCIRC   DOC1    CAOC1   GAPOC1  +PAER
PAERO4  1000    0       0       2       13      0.      0.      0.
$                                                                       $
$        THIS AEFACT ENTRY AND ITS CONTINUATION CONTAIN SIX FIELDS      $
$        FOR EACH MACH NO. ON THE MKAERO ENTRY; THE MACH NO. AND FIVE   $
$        CONSTANTS USED TO APPROXIMATE THEODORSENS CIRCULATION FUNC-    $
$        TION.  IN THIS CASE THE APPROXIMATION OF W.P. JONES IS USED    $
$        AT MACH NO. 0.0.                                               $
$                                                                       $
$       SID     D1      D2      D3      ETC
AEFACT  13      0.0     1.0     -0.165  0.041   -0.335  0.320
$                                                                       $
$        THE PAERO4 ENTRY DEFINES PROPERTIES OF THE STRIP ELEMENTS      $
$        FOR STRIP THEORY AERODYNAMICS.  IT OFFERS A WIDE VARIETY       $
$        OF OPTIONS.  CLA DEFAULTS TO NO COMPRESSIBILITY CORRECTION     $
$        AND NO CORRECTIONS OF LIFT CURVE SLOPES.  LCLA MUST BE ZERO    $
$        WHEN CLA IS ZERO.  CIRC=0 SPECIFIES THE EXACT EXPRESSION FOR   $
$        THE THEODORSEN CIRCULATION FUNCTION.  DOC, CAOC AND GAPOC      $
$        ARE REQUIRED EVEN THOUGH THE STRIP HAS NO CONTROL SURFACE.     $
$        IN FRACTIONS OF CHORD THESE ARE THE DISTANCE FROM THE QUARTER  $
$        CHORD TO THE HINGE LINE, THE CONTROL SURFACE CHORD AND THE     $
$        GAP BETWEEN THE PRIMARY SURFACE AND THE CONTROL SURFACE.       $
$        CAOC1=0. SPECIFIES NO CONTROL SURFACE.                         $
$                                                                       $
$        AN ALTERNATE METHOD WOULD BE TO SET CIRC=0 TO SPECIFY THE      $
$        EXACT EXPRESSION FOR THE THEODORSEN CIRCULATION FUNCTION       $
$        (SEE EXAMPLE HA75BAHK).                                        $
$                                                                       $
```

Listing 8-1 Input Files for Three Degree of Freedom Airfoil and Fuselage (Continued)

```
$       PID     CLA     LCLA    CIRC    LCIRC   DOC1    CAOC1   GAPOC1  +PAER
$PAERO4 1000    0       0       0       0       0.      0.      0.
$                                                                       $
$                   * * * SOLUTION SPECIFICATIONS * * *                 $
$                                                                       $
$                      * * AERODYNAMIC CONDITIONS * *                   $
$                                                                       $
$        ALL COMBINATIONS OF MACH NUMBER AND REDUCED FREQUENCY LISTED   $
$        ON THE MKAERO1 ENTRY AND ITS CONTINUATION WILL BE USED TO      $
$        GENERATE GENERALIZED AERO FORCE MATRICES.  IF MORE THAN EIGHT  $
$        MACH NOS OR REDUCED FREQUENCIES ARE REQUIRED A SECOND MKAERO1  $
$        IS NECESSARY.                                                  $
$                                                                       $
MKAERO1 0.                                                              +MK
$        K1      K2      K3      K4      K5      ETC
+MK     .001    .1      .2      .3      .4      .5      .6      .7
MKAERO1 0.                                                              +MKA
+MKA    .8      .9      1.      1.1     1.3     1.5     2.      5.
$                                                                       $
$                                                                       $
$                  * * VIBRATION SOLUTION PARAMETERS * *                $
$                                                                       $
$        THE EIGR ENTRY SPECIFIES THE METHOD OF EXTRACTING THE EIGEN-   $
$        SOLUTIONS OF THE STRUCTURE IN A VACUUM; IN THIS CASE THE       $
$        MODIFIED GIVENS METHOD.  THREE MODES ARE DESIRED, NORMAL-      $
$        IZED ON THE MAXIMUM DISPLACEMENTS.                             $
$                                                                       $
$       SID     METHOD  F1      F2              NO                      $
EIGR    1       MGIV    0.      25.             3                       +EGR
$       NORM    G       C                                               $
+EGR    MAX
$                                                                       $
$                  * * FLUTTER SOLUTION PARAMETERS * *                  $
$                                                                       $
$        THE FLUTTER ENTRY DEFINES THE METHOD OF SOLUTION, IDENTIFIES   $
$        THE FLFACT ENTRIES THAT FOLL0W, SPECIFIES THE INTERPOLATION    $
$        METHOD, THE NUMBER OF ROOTS DESIRED IN THE OUTPUT AND THE      $
$        CRITERION FOR CONVERGENCE (DEFAULT IS 10-3).                   $
$                                                                       $
$       SID     METHOD  DENS    MACH    VEL     IMETH   NVALUE  EPS     $
FLUTTER 3       PK      1       2       3       L       3
$                                                                       $
$        FLFACT ENTRIES ARE USED TO SPECIFY DENSITY RATIOS, MACH NOS    $
$        AND REDUCED FREQUENCIES/VELOCITIES FOR FLUTTER ANALYSES.       $
$        NEGATIVE VELOCITIES ARE SIGNALS TO COMPUTE AND PRINT EIGEN-    $
$        VECTORS.                                                       $
$                                                                       $
$       SID     F1      F2      F3      F4      F5      F6      F7      $
FLFACT  1       1.                                                      DENSITY
FLFACT  2       0.                                                      MACH NO.
FLFACT  3       20.     40.     60.     80.     100.    120.    140.    +FLF1
+FLF1   160.    170.    180.    190.    200.    210.    220.    -230.   +FLF2
+FLF2   -240.   260.    -280.   -290.   300.                            VELOCITY
$                                                                       $
$        THE EIGC ENTRY DEFINES DATA NEEDED TO PERFORM A COMPLEX        $
$        EIGENVALUE ANALYSIS.  THIS ONE SPECIFIES THAT THE UPPER        $
$        HESSENBERG METHOD BE USED TO EXTRACT COMPLEX EIGENVALUES       $
$        AND THAT THE EIGENVECTORS BE NORMALIZED ON THEIR MAXIMUM       $
$        COMPONENTS.  IF THEY WERE TO HAVE BEEN NORMALIZED ON A         $
$        POINT THE GRID AND DOF COMPONENT WOULD HAVE BEEN REQUIRED.     $
$        THE CONVERGENCE CRITERION DEFAULTS TO 1.0-4 FOR THE INVERSE    $
$        POWER METHOD, TO 1.0-11 FOR THE DETERMINANT METHOD AND TO      $
$        1.0-15 FOR THE HESSENBERG METHOD.  WHEN THE HESSENBERG         $
$        METHOD IS SPECIFIED ALL ENTRIES ON THE CONTINUATION ENTRY      $
$        EXCEPT THE NUMBER OF DESIRED ROOTS (NDL) ARE IGNORED.          $
```

Listing 8-1 Input Files for Three Degree of Freedom Airfoil and Fuselage (Continued)

```
$       SID     METHOD  NORM    G       C       E
EIGC    20      HESS    MAX                                     +EC
$       ALPHAA1 OMEGAA1 ALPHAB1 OMEGAB1 L1      NEL     NDL
+EC                                                     6
$
$        NOTE THE ABSENCE OF A PARAM,LMODES,N ENTRY TO STIPULATE THE    $
$        NO. OF MODES TO BE USED IN THE ANALYSIS.  LMODES DEFAULTS      $
$        TO ZERO BUT THE PROGRAM THEN INTERROGATES LFREQ AND HFREQ      $
$        WHICH DEFINE THE FREQUENCY RANGE OF INTEREST; LFREQ DEFAULTS   $
$        TO ZERO AND HFREQ DEFAULTS TO 1.0E30.  AS A RESULT ALL MODES   $
$        ARE INCLUDED.                                                  $
$                                                                       $
ENDDATA
```

Listing 8-2 Bulk Data Entries for Three Degree of Freedom Airfoil and Fuselage

```
                           S O R T E D   B U L K   D A T A   E C H O
ENTRY
COUNT        .  1  ..  2  ..  3  ..  4  ..  5  ..  6  ..  7  ..  8  ..  9  ..  10  .
   1-         AEFACT  13      0.      1.      -.165   .041    -.335   .32
   2-         AERO            100.    6.      .002378 0       0
   3-         CAERO4  1000    1000            1                                        +
   4-         +       -2.4    0.      0.      6.      -2.4    1.      0.      6.
   5-         CDAMP2  123     .40341  100     3       102     3
   6-         CDAMP2  125     2.2692  100     5
   7-         CELAS2  103     134.47  100     3       102     3
   8-         CELAS2  105     1891.   100     5
   9-         CMASS2  111     1.3447  102     3
   10-         CONM1   110     100                                                     +
   11-         +       1.3447                                                  .24205  +
   12-         +               3.0256
   13-         EIGC    20      HESS    MAX                                             +
   14-         +                                                       6
   15-         EIGR    1       MGIV    0.      25.             3                       +
   16-         +       MAX
   17-         FLFACT  1       1.
   18-         FLFACT  2       0.
   19-         FLFACT  3       20.     40.     60.     80.     100.    120.    140.    +
   20-         +       160.    170.    180.    190.    200.    210.    220.    -230.   +
   21-         +       -240.   260.    -280.   -290.   300.
   22-         FLFACT  4       .2      .18     .16     .14     .12     .1      .08     +
   23-         +       .06
   24-         FLUTTER 3       PK      1       2       3       L       3
   25-         FLUTTER 4       K       1       2       4       L       3
   26-         GRID    100             0.      .5      0.              1246
   27-         GRID    101             0.      1.      0.
   28-         GRID    102             0.      .5      0.              12456
   29-         MDLPRM  HDF5    1
   30-         MKAERO1 0.                                                              +
   31-         +       .001    .1      .2      .3      .4      .5      .6      .7
   32-         MKAERO1 0.                                                              +
   33-         +       .8      .9      1.      1.1     1.3     1.5     2.      5.
   34-         PAERO4  1000    0       0       2       13      0.      0.      0.
   35-         PARAM   OGEOM   NO
   36-         PARAM   OPPHIPA 1
   37-         PARAM   POST    -1
   38-         RBAR    101     100     101     123456
   39-         SET1    1100    100     101
   40-         SPLINE2 1201    1000    1000    1000    1100    0.      1.      0       +
   41-         +       0.      0.
   ENDDATA
   TOTAL COUNT= 42
```

Listing 8-3 Output for Three Degree of Freedom Airfoil and Fuselage

```
1 EXAMPLE HA145A: THREE DEGREE OF FREEDOM AEROELASTIC MO HA145A JANUARY  29, 2022  MSC Nastran  1/27/22 PAGE    14
     2-D AERO, W.P. JONES C(K) WITH PK- AND K- FLUTTER METHODS
0     ONE RIGID BODY AND TWO FLEXIBLE MODES, C.G. AT 0.37 CHORD                                                  SUBCASE 1

                                              R E A L   E I G E N V A L U E S
                                           (BEFORE AUGMENTATION OF RESIDUAL VECTORS)
   MODE    EXTRACTION      EIGENVALUE            RADIANS             CYCLES            GENERALIZED         GENERALIZED
    NO.       ORDER                                                                       MASS              STIFFNESS
        1         1       -5.968228E-15        7.725431E-08        1.229541E-08        2.689400E+00       -1.605095E-14
        2         2        1.993302E+02        1.411843E+01        2.247019E+00        2.693529E+00        5.369017E+02
        3         3        6.362626E+02        2.522425E+01        4.014564E+00        2.986609E+00        1.900267E+03

      EIGENVALUE = -5.968228E-15
          CYCLES =  1.229541E-08         R E A L   E I G E N V E C T O R   N O .          1

      POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
           100      G      0.0            0.0            1.000000E+00   0.0            6.790353E-17   0.0
           101      G      0.0            0.0            1.000000E+00   0.0            6.790353E-17   0.0
           102      G      0.0            0.0            1.000000E+00   0.0            0.0            0.0

      EIGENVALUE =  1.993302E+02
          CYCLES =  2.247019E+00         R E A L   E I G E N V E C T O R   N O .          2

      POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
           100      G      0.0            0.0           -9.933019E-01   0.0           -3.721132E-02   0.0
           101      G      0.0            0.0           -9.933019E-01   0.0           -3.721132E-02   0.0
           102      G      0.0            0.0            1.000000E+00   0.0            0.0            0.0

      EIGENVALUE =  6.362626E+02
          CYCLES =  4.014564E+00         R E A L   E I G E N V E C T O R   N O .          3

      POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
           100      G      0.0            0.0           -2.212632E-01   0.0            1.000000E+00   0.0
           101      G      0.0            0.0           -2.212632E-01   0.0            1.000000E+00   0.0
           102      G      0.0            0.0            4.126023E-02   0.0            0.0            0.0

      EIGENVALUE = -5.968228E-15
          CYCLES =  1.229541E-08         R E A L   E I G E N V E C T O R   N O .          1

      POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
          1000      G      0.0            0.0            1.000000E+00   0.0            6.790353E-17   0.0

      EIGENVALUE =  1.993302E+02
          CYCLES =  2.247019E+00         R E A L   E I G E N V E C T O R   N O .          2

      POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
          1000      G      0.0            0.0           -1.026792E+00   0.0           -3.721132E-02   0.0

      EIGENVALUE =  6.362626E+02
          CYCLES =  4.014564E+00         R E A L   E I G E N V E C T O R   N O .          3

      POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
          1000      G      0.0            0.0            6.787368E-01   0.0            1.000000E+00   0.0

 A ZERO FREQUENCY ROOT HAS EMERGED.  WHEN THE MACH NO., DENSITY AND VELOCITY ARE COMPATIBLE
 IT MAY BE INTERPRETED TWO WAYS DEPENDING ON THE SIGN OF THE REAL PART:
   1. (-) A MODE IS CRITICALLY DAMPED, OR,
   2. (+) THE SYSTEM IS DIVERGING.
 ONLY THE MOST CRITICAL ( I.E., MOST POSITIVE REAL ROOTS )  ARE PRINTED IN THE FLUTTER SUMMARY.
 FOR INFORMATIONAL PURPOSES, THE REMAINING REAL ROOTS ARE PRINTED HERE.

      LESS CRITICAL REAL ROOTS FOR LOOP   15      MACH         VELOCITY        DENSITY
                                               0.00000E+00    2.30000E+02    1.00000E+00

         KFREQ          DAMPING                  COMPLEX EIGENVALUE

        0.0000     -1.9090311E+00       -5.0723657E+01        0.0000000E+00


                                               EIGENVECTOR FROM THE    PK METHOD
   EIGENVALUE =    -2.08241E-04    0.00000E+00       VELOCITY =     2.30000E+02

   EIGENVECTOR
                    1.00000E+00    0.00000E+00
                   -1.62832E-10    0.00000E+00
                    3.06577E-11    0.00000E+00

1    EXAMPLE HA145A: THREE DEGREE OF FREEDOM AEROELASTIC MO HA145A JANUARY  29, 2022  MSC Nastran  1/27/22   PAGE    26
     2-D AERO, W.P. JONES C(K) WITH PK- AND K- FLUTTER METHODS
0    ONE RIGID BODY AND TWO FLEXIBLE MODES, C.G. AT 0.37 CHORD                                            SUBCASE 1
```

Listing 8-3 Output for Three Degree of Freedom Airfoil and Fuselage (Continued)

```
                                                  EIGENVECTOR FROM THE    PK METHOD
   EIGENVALUE =    -1.18325E-01    7.43723E+00       VELOCITY =      2.30000E+02

   EIGENVECTOR
                    1.00000E+00    0.00000E+00
                    3.95235E-01    3.01039E-03
                   -5.82376E-02    1.29436E-02


                                              EIGENVECTOR FROM THE    PK METHOD
   EIGENVALUE =    -9.25938E-01    1.73208E+01       VELOCITY =      2.30000E+02

   EIGENVECTOR
                   -3.31951E-01   -4.05016E-02
                    1.00000E+00    0.00000E+00
                    1.79577E-01   -6.95897E-02

      LESS CRITICAL REAL ROOTS FOR LOOP   16      MACH        VELOCITY        DENSITY
                                              0.00000E+00    2.40000E+02    1.00000E+00

         KFREQ          DAMPING                 COMPLEX EIGENVALUE

        0.0000     -1.9398968E+00       -5.3784802E+01        0.0000000E+00


                                              EIGENVECTOR FROM THE    PK METHOD
   EIGENVALUE =    -2.17294E-04    0.00000E+00       VELOCITY =      2.40000E+02

   EIGENVECTOR
                    1.00000E+00    0.00000E+00
                   -2.31650E-10    0.00000E+00
                    4.35327E-11    0.00000E+00


                                              EIGENVECTOR FROM THE    PK METHOD
   EIGENVALUE =     4.62465E-01    7.20415E+00       VELOCITY =      2.40000E+02

   EIGENVECTOR
                    1.00000E+00    0.00000E+00
                    3.53160E-01   -7.44978E-02
                   -5.05852E-02    2.01762E-02
1    EXAMPLE HA145A: THREE DEGREE OF FREEDOM AEROELASTIC MO HA145A         JANUARY  29, 2022  MSC Nastran  1/27/22   PAGE    27
      2-D AERO, W.P. JONES C(K) WITH PK- AND K- FLUTTER METHODS
0     ONE RIGID BODY AND TWO FLEXIBLE MODES, C.G. AT 0.37 CHORD                                                  SUBCASE 1


                                              EIGENVECTOR FROM THE    PK METHOD
   EIGENVALUE =    -7.05612E-01    1.72429E+01       VELOCITY =      2.40000E+02

   EIGENVECTOR
                   -3.23849E-01   -2.39198E-02
                    1.00000E+00    0.00000E+00
                    1.60379E-01   -7.70251E-02

      LESS CRITICAL REAL ROOTS FOR LOOP   17      MACH        VELOCITY        DENSITY
                                              0.00000E+00    2.60000E+02    1.00000E+00

         KFREQ          DAMPING                 COMPLEX EIGENVALUE

        0.0000     -1.9894429E+00       -5.9755038E+01        0.0000000E+00

      LESS CRITICAL REAL ROOTS FOR LOOP   18      MACH        VELOCITY        DENSITY
                                              0.00000E+00    2.80000E+02    1.00000E+00

         KFREQ          DAMPING                 COMPLEX EIGENVALUE

        0.0000     -2.0272429E+00       -6.5574279E+01        0.0000000E+00


                                              EIGENVECTOR FROM THE    PK METHOD
EIGENVALUE =    -2.53504E-04    0.00000E+00       VELOCITY =      2.80000E+02

   EIGENVECTOR
                    1.00000E+00    0.00000E+00
                   -3.25428E-10    0.00000E+00
                    6.11443E-11    0.00000E+00


                                              EIGENVECTOR FROM THE    PK METHOD
   EIGENVALUE =     2.07290E+00    6.43864E+00       VELOCITY =      2.80000E+02

   EIGENVECTOR
                    1.00000E+00    0.00000E+00
                    1.93893E-01   -2.05346E-01
                   -2.77840E-02    3.28280E-02
```

Main Index

Listing 8-3 Output for Three Degree of Freedom Airfoil and Fuselage (Continued)

```
                                                   EIGENVECTOR FROM THE    PK METHOD
   EIGENVALUE =    -4.15510E-02    1.69432E+01       VELOCITY =     2.80000E+02

   EIGENVECTOR
                   -3.00057E-01    2.78657E-02
                    1.00000E+00    0.00000E+00
                    1.06922E-01   -8.76489E-02

1    EXAMPLE HA145A: THREE DEGREE OF FREEDOM AEROELASTIC MO HA145A         JANUARY  29, 2022  MSC Nastran  1/27/22   PAGE    28
      2-D AERO, W.P. JONES C(K) WITH PK- AND K- FLUTTER METHODS
0     ONE RIGID BODY AND TWO FLEXIBLE MODES, C.G. AT 0.37 CHORD                                              SUBCASE 1

LESS CRITICAL REAL ROOTS FOR LOOP   19      MACH        VELOCITY        DENSITY
                                              0.00000E+00    2.90000E+02    1.00000E+00

         KFREQ          DAMPING                COMPLEX EIGENVALUE

        0.0000     -2.0428987E+00       -6.8440717E+01        0.0000000E+00

                                                   EIGENVECTOR FROM THE    PK METHOD
   EIGENVALUE =    -2.62556E-04    0.00000E+00       VELOCITY =     2.90000E+02

   EIGENVECTOR
                    1.00000E+00    0.00000E+00
                   -3.49590E-10    0.00000E+00
                    6.56835E-11    0.00000E+00

                                                   EIGENVECTOR FROM THE    PK METHOD
   EIGENVALUE =     2.37985E+00    6.26079E+00       VELOCITY =     2.90000E+02

   EIGENVECTOR
                    1.00000E+00    0.00000E+00
                    1.61109E-01   -2.16203E-01
                   -2.32813E-02    3.39189E-02

                                                   EIGENVECTOR FROM THE    PK METHOD
   EIGENVALUE =     7.30872E-02    1.68646E+01       VELOCITY =     2.90000E+02

   EIGENVECTOR
                   -2.94100E-01    3.75510E-02
                    1.00000E+00    0.00000E+00
                    9.73901E-02   -8.70023E-02
      LESS CRITICAL REAL ROOTS FOR LOOP   20      MACH        VELOCITY        DENSITY
                                              0.00000E+00    3.00000E+02    1.00000E+00

         KFREQ          DAMPING                COMPLEX EIGENVALUE

        0.0000     -2.0568278E+00       -7.1283482E+01        0.0000000E+00
0                                                     FLUTTER  SUMMARY
                             CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = ASYMMETRIC
       POINT =    1     MACH NUMBER =  0.0000      DENSITY RATIO =  1.0000E+00     METHOD = PK

       KFREQ           1./KFREQ         VELOCITY          DAMPING          FREQUENCY           COMPLEX   EIGENVALUE
        0.0000      1.0000000E+25    2.0000000E+01    -7.8377719E-06     0.0000000E+00    -1.8108911E-05     0.0000000E+00
        0.0000      1.0000000E+25    4.0000000E+01    -7.8377621E-06     0.0000000E+00    -3.6217776E-05     0.0000000E+00
        0.0000      1.0000000E+25    6.0000000E+01    -7.8377457E-06     0.0000000E+00    -5.4326551E-05     0.0000000E+00
        0.0000      1.0000000E+25    8.0000000E+01    -7.8377229E-06     0.0000000E+00    -7.2435190E-05     0.0000000E+00
        0.0000      1.0000000E+25    1.0000000E+02    -7.8376936E-06     0.0000000E+00    -9.0543649E-05     0.0000000E+00
        0.0000      1.0000000E+25    1.2000000E+02    -7.8376577E-06     0.0000000E+00    -1.0865188E-04     0.0000000E+00
        0.0000      1.0000000E+25    1.4000000E+02    -7.8376153E-06     0.0000000E+00    -1.2675984E-04     0.0000000E+00
        0.0000      1.0000000E+25    1.6000000E+02    -7.8375663E-06     0.0000000E+00    -1.4486749E-04     0.0000000E+00
        0.0000      1.0000000E+25    1.7000000E+02    -7.8375394E-06     0.0000000E+00    -1.5392118E-04     0.0000000E+00
        0.0000      1.0000000E+25    1.8000000E+02    -7.8375109E-06     0.0000000E+00    -1.6297477E-04     0.0000000E+00
        0.0000      1.0000000E+25    1.9000000E+02    -7.8374807E-06     0.0000000E+00    -1.7202826E-04     0.0000000E+00
        0.0000      1.0000000E+25    2.0000000E+02    -7.8374489E-06     0.0000000E+00    -1.8108164E-04     0.0000000E+00
        0.0000      1.0000000E+25    2.1000000E+02    -7.8374155E-06     0.0000000E+00    -1.9013492E-04     0.0000000E+00
        0.0000      1.0000000E+25    2.2000000E+02    -7.8373804E-06     0.0000000E+00    -1.9918807E-04     0.0000000E+00
        0.0000      1.0000000E+25    2.3000000E+02    -7.8373437E-06     0.0000000E+00    -2.0824110E-04     0.0000000E+00
        0.0000      1.0000000E+25    2.4000000E+02    -7.8373054E-06     0.0000000E+00    -2.1729399E-04     0.0000000E+00
        0.0000      1.0000000E+25    2.6000000E+02    -7.8372238E-06     0.0000000E+00    -2.3539938E-04     0.0000000E+00
        0.0000      1.0000000E+25    2.8000000E+02    -7.8371357E-06     0.0000000E+00    -2.5350417E-04     0.0000000E+00
        0.0000      1.0000000E+25    2.9000000E+02    -7.8370893E-06     0.0000000E+00    -2.6255634E-04     0.0000000E+00
        0.0000      1.0000000E+25    3.0000000E+02    -7.8370412E-06     0.0000000E+00    -2.7160834E-04     0.0000000E+00
```

Listing 8-3 Output for Three Degree of Freedom Airfoil and Fuselage (Continued)

```
0                                                    FLUTTER  SUMMARY
                          CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = ASYMMETRIC
      POINT =    2      MACH NUMBER =  0.0000     DENSITY RATIO =  1.0000E+00     METHOD = PK

      KFREQ          1./KFREQ        VELOCITY          DAMPING          FREQUENCY          COMPLEX   EIGENVALUE
       2.0932       4.7773999E-01    2.0000000E+01   -5.2890307E-02    2.2209423E+00   -3.6903133E-01    1.3954592E+01
       1.0467       9.5538123E-01    4.0000000E+01   -6.4871054E-02    2.2211719E+00   -4.5267133E-01    1.3956034E+01
       0.6975       1.4336575E+00    6.0000000E+01   -8.0391747E-02    2.2202645E+00   -5.6074584E-01    1.3950333E+01
       0.5223       1.9144516E+00    8.0000000E+01   -1.0105664E-01    2.2168917E+00   -7.0381610E-01    1.3929141E+01
       0.4165       2.4010505E+00    1.0000000E+02   -1.2927177E-01    2.2095182E+00   -8.9732788E-01    1.3882812E+01
       0.3448       2.8999091E+00    1.2000000E+02   -1.6789274E-01    2.1953094E+00   -1.1579173E+00    1.3793536E+01
       0.2923       3.4214360E+00    1.4000000E+02   -2.2941399E-01    2.1707934E+00   -1.5645457E+00    1.3639497E+01
       0.2500       4.0006932E+00    1.6000000E+02   -3.4224748E-01    2.1216982E+00   -2.2812545E+00    1.3331023E+01
       0.2288       4.3697591E+00    1.7000000E+02   -4.3594974E-01    2.0639078E+00   -2.8266777E+00    1.2967915E+01
       0.2032       4.9216230E+00    1.8000000E+02   -5.5297875E-01    1.9402739E+00   -3.3707097E+00    1.2191100E+01
       0.1739       5.7502491E+00    1.9000000E+02   -6.2116540E-01    1.7529350E+00   -3.4207627E+00    1.1014016E+01
       0.1441       6.9417572E+00    2.0000000E+02   -6.0905172E-01    1.5284789E+00   -2.9245800E+00    9.6037163E+00
       0.1187       8.4225058E+00    2.1000000E+02   -4.4093303E-01    1.3227472E+00   -1.8323117E+00    8.3110658E+00
       0.1056       9.4713082E+00    2.2000000E+02   -2.1867699E-01    1.2322862E+00   -8.4657326E-01    7.7426826E+00
       0.0970       1.0308494E+01    2.3000000E+02   -3.1819677E-02    1.1836723E+00   -1.1832517E-01    7.4372324E+00
       0.0901       1.1104705E+01    2.4000000E+02    1.2838847E-01    1.1465767E+00    4.6246515E-01    7.2041537E+00
       0.0784       1.2752676E+01    2.6000000E+02    4.0187505E-01    1.0816105E+00    1.3655633E+00    6.7959594E+00
       0.0690       1.4495813E+01    2.8000000E+02    6.4389269E-01    1.0247415E+00    2.0728968E+00    6.4386407E+00
       0.0648       1.5440003E+01    2.9000000E+02    7.6024060E-01    9.9643618E-01    2.3798546E+00    6.2607931E+00
       0.0608       1.6444989E+01    3.0000000E+02    8.7611648E-01    9.6780208E-01    2.6637795E+00    6.0808798E+00
0                                                    FLUTTER  SUMMARY
                          CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = ASYMMETRIC
      POINT =    3      MACH NUMBER =  0.0000     DENSITY RATIO =  1.0000E+00     METHOD = PK

      KFREQ          1./KFREQ        VELOCITY          DAMPING          FREQUENCY          COMPLEX   EIGENVALUE
       3.6983       2.7039259E-01    2.0000000E+01   -6.2587998E-02    3.9240459E+00   -7.7156943E-01    2.4655508E+01
       1.8393       5.4368530E-01    4.0000000E+01   -9.5471612E-02    3.9031144E+00   -1.1706725E+00    2.4523991E+01
       1.2128       8.2455850E-01    6.0000000E+01   -1.3017436E-01    3.8603675E+00   -1.5787159E+00    2.4255405E+01
       0.8947       1.1176723E+00    8.0000000E+01   -1.6754294E-01    3.7972952E+00   -1.9987127E+00    2.3859110E+01
       0.6992       1.4301564E+00    1.0000000E+02   -2.0801635E-01    3.7094998E+00   -2.4241679E+00    2.3307475E+01
       0.5641       1.7726381E+00    1.2000000E+02   -2.5113462E-01    3.5913692E+00   -2.8334562E+00    2.2565238E+01
       0.4623       2.1629749E+00    1.4000000E+02   -2.9649172E-01    3.4338034E+00   -3.1984375E+00    2.1575223E+01
       0.3808       2.6258377E+00    1.6000000E+02   -3.2693555E-01    3.2325927E+00   -3.3201905E+00    2.0310979E+01
       0.3459       2.8913375E+00    1.7000000E+02   -3.2582738E-01    3.1192415E+00   -3.1929083E+00    1.9598773E+01
       0.3141       3.1834201E+00    1.8000000E+02   -3.0907881E-01    2.9996973E+00   -2.9127053E+00    1.8847654E+01
       0.2872       3.4813390E+00    1.9000000E+02   -2.6960139E-01    2.8953840E+00   -2.4523258E+00    1.8192234E+01
       0.2668       3.7474433E+00    2.0000000E+02   -2.1918355E-01    2.8313516E+00   -1.9496275E+00    1.7789907E+01
       0.2510       3.9843529E+00    2.1000000E+02   -1.7416044E-01    2.7961494E+00   -1.5298884E+00    1.7568725E+01
       0.2376       4.2080055E+00    2.2000000E+02   -1.3744660E-01    2.7736091E+00   -1.1976478E+00    1.7427100E+01
       0.2259       4.4262865E+00    2.3000000E+02   -1.0691658E-01    2.7566853E+00   -9.2593842E-01    1.7320764E+01
       0.2155       4.6395958E+00    2.4000000E+02   -8.1843876E-02    2.7442898E+00   -7.0561212E-01    1.7242881E+01
       0.1972       5.0715085E+00    2.6000000E+02   -3.8695966E-02    2.7197881E+00   -3.3063637E-01    1.7088933E+01
       0.1815       5.5086004E+00    2.8000000E+02   -4.9047395E-03    2.6965945E+00   -4.1550998E-02    1.6943203E+01
       0.1745       5.7319327E+00    2.9000000E+02    8.6675366E-03    2.6840821E+00    7.3087204E-02    1.6864585E+01
       0.1678       5.9587002E+00    3.0000000E+02    1.9939182E-02    2.6709674E+00    1.6731151E-01    1.6782183E+01
COMPLEX EIGENVALUE = -1.183252E-01,  7.437232E+00
                                           C O M P L E X   E I G E N V E C T O R   NO.         2
                                                            (REAL/IMAGINARY)

     POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
0        100      G      0.0            0.0            6.202982E-01   0.0           -7.294481E-02   0.0
                         0.0            0.0           -5.854168E-03   0.0            1.283158E-02   0.0
0        101      G      0.0            0.0            6.202982E-01   0.0           -7.294481E-02   0.0
                         0.0            0.0           -5.854168E-03   0.0            1.283158E-02   0.0
0        102      G      0.0            0.0            1.392832E+00   0.0            0.0            0.0
                         0.0            0.0            3.544446E-03   0.0            0.0            0.0

     COMPLEX EIGENVALUE =  4.624651E-01,  7.204154E+00
                                           C O M P L E X   E I G E N V E C T O R   NO.         5
                                                            (REAL/IMAGINARY)

     POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
0        100      G      0.0            0.0            6.603984E-01   0.0           -6.372675E-02   0.0
                         0.0            0.0            6.953454E-02   0.0            2.294834E-02   0.0
0        101      G      0.0            0.0            6.603984E-01   0.0           -6.372675E-02   0.0
                         0.0            0.0            6.953454E-02   0.0            2.294834E-02   0.0
0        102      G      0.0            0.0            1.351073E+00   0.0            0.0            0.0
                         0.0            0.0           -7.366531E-02   0.0            0.0            0.0
COMPLEX EIGENVALUE = -4.155100E-02,  1.694320E+01
                                           C O M P L E X   E I G E N V E C T O R   NO.         9
                                                            (REAL/IMAGINARY)

     POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
0        100      G      0.0            0.0           -1.317017E+00   0.0            6.971086E-02   0.0
                         0.0            0.0            4.725915E-02   0.0           -8.764888E-02   0.0
0        101      G      0.0            0.0           -1.317017E+00   0.0            6.971086E-02   0.0
                         0.0            0.0            4.725915E-02   0.0           -8.764888E-02   0.0
0        102      G      0.0            0.0            7.043546E-01   0.0            0.0            0.0
                         0.0            0.0            2.424927E-02   0.0            0.0            0.0

     COMPLEX EIGENVALUE =  7.308720E-02,  1.686459E+01
```

Listing 8-3 Output for Three Degree of Freedom Airfoil and Fuselage (Continued)

```
 C O M P L E X   E I G E N V E C T O R   NO.        12
                                                    (REAL/IMAGINARY)

      POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
0         100      G      0.0            0.0           -1.308951E+00   0.0            6.017874E-02   0.0
                          0.0            0.0            5.680138E-02   0.0           -8.700234E-02   0.0
0         101      G      0.0            0.0           -1.308951E+00   0.0            6.017874E-02   0.0
                          0.0            0.0            5.680138E-02   0.0           -8.700234E-02   0.0
0         102      G      0.0            0.0            7.099184E-01   0.0            0.0            0.0
                          0.0            0.0            3.396122E-02   0.0            0.0            0.0

0                                                    FLUTTER  SUMMARY
                    CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = ASYMMETRIC
      POINT =     1     MACH NUMBER =  0.0000     DENSITY RATIO =  1.0000E+00     METHOD = K


      KFREQ          1./KFREQ        VELOCITY          DAMPING         FREQUENCY           COMPLEX   EIGENVALUE
       0.2000       5.0000000E+00    STABLE-SYSTEM-    STABLE-SYSTEM-    STABLE-SYSTEM-    -1.9761795E-13    -3.7833945E-14
       0.2000       5.0000000E+00     1.8277670E+02    -2.8949067E-01     1.9393210E+00    -2.5155736E+01     1.7736100E+02
       0.2000       5.0000000E+00     2.5796811E+02    -3.4388412E-02     2.7371267E+00    -4.4322816E+00     2.5785381E+02
 *** USER INFORMATION MESSAGE 6142 (FA2)
    THE K OR KE METHOD OF FLUTTER ANALYSIS HAS FOUND A ROOT THAT HAS NO PHYSICAL INTERPRETATION.
    NOTE THAT TO OBTAIN PHYSICALLY MEANINGFUL V-G AND V-F PLOTS, XMIN,XMAX,YMIN,YMAX VALUES
    MUST BE EXPLICITLY SET IN THIS CASE.

0                                                    FLUTTER  SUMMARY
                    CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = ASYMMETRIC
      POINT =     2     MACH NUMBER =  0.0000     DENSITY RATIO =  1.0000E+00     METHOD = K


      KFREQ          1./KFREQ        VELOCITY          DAMPING         FREQUENCY           COMPLEX   EIGENVALUE
       0.1800       5.5555556E+00     1.6508516E-16     8.3589121E-01     1.5764472E-18     4.9329073E-17    -1.3592915E-16
       0.1800       5.5555556E+00     1.9263012E+02    -2.8513794E-01     1.8394821E+00    -2.6151130E+01     1.8708341E+02
       0.1800       5.5555556E+00     2.8148335E+02    -1.1312528E-02     2.6879680E+00    -1.5920168E+00     2.8146985E+02
0                                                    FLUTTER  SUMMARY
                    CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = ASYMMETRIC
      POINT =     3     MACH NUMBER =  0.0000     DENSITY RATIO =  1.0000E+00     METHOD = K


      KFREQ          1./KFREQ        VELOCITY          DAMPING         FREQUENCY           COMPLEX   EIGENVALUE
       0.1600       6.2500000E+00     2.0193666E-16     7.5122328E-01     1.7140916E-18     5.7166553E-17    -1.7127627E-16
       0.1600       6.2500000E+00     2.0233513E+02    -2.6253783E-01     1.7174739E+00    -2.5474796E+01     1.9735405E+02
       0.1600       6.2500000E+00     3.1127688E+02     5.7933726E-03     2.6422003E+00     9.0165257E-01     3.1127297E+02

0                                                    FLUTTER  SUMMARY
                    CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = ASYMMETRIC
      POINT =     4     MACH NUMBER =  0.0000     DENSITY RATIO =  1.0000E+00     METHOD = K


      KFREQ          1./KFREQ        VELOCITY          DAMPING         FREQUENCY           COMPLEX   EIGENVALUE
       0.1400       7.1428571E+00     2.5205078E-16     6.7160346E-01     1.8720393E-18     6.6923726E-17    -2.1968286E-16
       0.1400       7.1428571E+00     2.1172806E+02    -2.1586068E-01     1.5725532E+00    -2.2209870E+01     2.0814950E+02
       0.1400       7.1428571E+00     3.4997595E+02     1.6471657E-02     2.5993521E+00     2.8818532E+00     3.4994035E+02

0                                                    FLUTTER  SUMMARY
                    CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = ASYMMETRIC
      POINT =     5     MACH NUMBER =  0.0000     DENSITY RATIO =  1.0000E+00     METHOD = K


      KFREQ          1./KFREQ        VELOCITY          DAMPING         FREQUENCY           COMPLEX   EIGENVALUE
       0.1200       8.3333333E+00     3.2143766E-16     5.9880797E-01     2.0463357E-18     7.9348970E-17    -2.8696403E-16
       0.1200       8.3333333E+00     2.2084438E+02    -1.3864927E-01     1.4059390E+00    -1.5128751E+01     2.1927431E+02
       0.1200       8.3333333E+00     4.0206173E+02     2.0703491E-02     2.5596044E+00     4.1609261E+00     4.0199712E+02

0                                                    FLUTTER  SUMMARY
                    CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = ASYMMETRIC
      POINT =     6     MACH NUMBER =  0.0000     DENSITY RATIO =  1.0000E+00     METHOD = K


      KFREQ          1./KFREQ        VELOCITY          DAMPING         FREQUENCY           COMPLEX   EIGENVALUE
       0.1000       1.0000000E+01     4.1867885E-16     5.3569306E-01     2.2211603E-18     9.5687624E-17    -3.8126318E-16
       0.1000       1.0000000E+01     2.3030865E+02    -2.2779399E-02     1.2218253E+00    -2.6222960E+00     2.3026385E+02
       0.1000       1.0000000E+01     4.7557442E+02     1.9180994E-02     2.5230007E+00     4.5599466E+00     4.7550883E+02

0                                                    FLUTTER  SUMMARY
                    CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = ASYMMETRIC
      POINT =     7     MACH NUMBER =  0.0000     DENSITY RATIO =  1.0000E+00     METHOD = K


      KFREQ          1./KFREQ        VELOCITY          DAMPING         FREQUENCY           COMPLEX   EIGENVALUE
       0.0800       1.2500000E+01     5.5461959E-16     4.8587640E-01     2.3538786E-18     1.1793919E-16    -5.1260513E-16
       0.0800       1.2500000E+01     2.4225985E+02     1.4543834E-01     1.0281827E+00     1.7387847E+01     2.4036735E+02
       0.0800       1.2500000E+01     5.8628583E+02     1.3180809E-02     2.4882744E+00     3.8634412E+00     5.8624764E+02
```

Listing 8-3 Output for Three Degree of Freedom Airfoil and Fuselage (Continued)

```
0                                                      FLUTTER  SUMMARY
                         CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = ASYMMETRIC
       POINT =     8     MACH NUMBER =  0.0000     DENSITY RATIO =  1.0000E+00     METHOD = K


       KFREQ           1./KFREQ         VELOCITY          DAMPING          FREQUENCY           COMPLEX   EIGENVALUE
        0.0600       1.6666667E+01    7.3670995E-16    4.4816690E-01    2.3450206E-18    1.4716271E-16    -6.8820055E-16
        0.0600       1.6666667E+01    2.6332545E+02    3.9871519E-01    8.3819095E-01    4.7855509E+01     2.4923722E+02
        0.0600       1.6666667E+01    7.7065448E+02    3.9373958E-03    2.4530694E+00    1.5171712E+00     7.7065000E+02

      COMPLEX EIGENVALUE = -1.592017E+00,  2.814698E+02

 C O M P L E X   E I G E N V E C T O R   NO.          6
                                                        (REAL/IMAGINARY)

      POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
0        100       G      0.0            0.0            1.312238E+00   0.0           -6.990545E-02   0.0
                          0.0            0.0           -4.216038E-02   0.0            8.371519E-02   0.0
0        101       G      0.0            0.0            1.312238E+00   0.0           -6.990545E-02   0.0
                          0.0            0.0           -4.216038E-02   0.0            8.371519E-02   0.0
0        102       G      0.0            0.0           -7.091847E-01   0.0            0.0            0.0
                          0.0            0.0           -2.018318E-02   0.0            0.0            0.0

      COMPLEX EIGENVALUE =  9.016526E-01,  3.112730E+02
                                      C O M P L E X   E I G E N V E C T O R   NO.          6
                                                        (REAL/IMAGINARY)

      POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
0        100       G      0.0            0.0            1.284193E+00   0.0           -4.898678E-02   0.0
                          0.0            0.0           -5.310397E-02   0.0            7.434588E-02   0.0
0        101       G      0.0            0.0            1.284193E+00   0.0           -4.898678E-02   0.0
                          0.0            0.0           -5.310397E-02   0.0            7.434588E-02   0.0
0        102       G      0.0            0.0           -7.317379E-01   0.0            0.0            0.0
                          0.0            0.0           -3.358643E-02   0.0            0.0            0.0

      COMPLEX EIGENVALUE = -2.622296E+00,  2.302639E+02
                                      C O M P L E X   E I G E N V E C T O R   NO.          5
                                                        (REAL/IMAGINARY)

      POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
0        100       G      0.0            0.0           -5.864448E-01   0.0            7.787640E-02   0.0
                          0.0            0.0            6.414954E-04   0.0           -1.511581E-02   0.0
0        101       G      0.0            0.0           -5.864448E-01   0.0            7.787640E-02   0.0
                          0.0            0.0            6.414954E-04   0.0           -1.511581E-02   0.0
0        102       G      0.0            0.0           -1.427573E+00   0.0            0.0            0.0
                          0.0            0.0            2.079394E-03   0.0            0.0            0.0

      COMPLEX EIGENVALUE =  1.738785E+01,  2.403673E+02
                                      C O M P L E X   E I G E N V E C T O R   NO.          5
                                                        (REAL/IMAGINARY)

      POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
0        100       G      0.0            0.0           -7.502419E-01   0.0            4.917356E-02   0.0
                          0.0            0.0           -5.191987E-02   0.0           -1.710421E-02   0.0
0        101       G      0.0            0.0           -7.502419E-01   0.0            4.917356E-02   0.0
                          0.0            0.0           -5.191987E-02   0.0           -1.710421E-02   0.0
0        102       G      0.0            0.0           -1.258609E+00   0.0            0.0            0.0
                          0.0            0.0            5.499868E-02   0.0            0.0            0.0
```

Flutter Analysis of Jet Transport Wing by Lifting Surface Theory (Example HA145B)

This example of the BAH wing is considered for its static aeroelastic characteristics in roll in Example HA144B (p. 240) and for its flutter characteristics using Strip Theory by Rodden (1959a) [Reference 40] and Rodden, Harder, and Bellinger (1979) [Reference 50]. The present analysis illustrates the use of the subsonic Doublet-Lattice method (DLM) in a flutter analysis by the PK-method. The model is shown in Figure 8-3.

For this example, the structural model is the same as discussed in Example HA144B (p. 240) except that the aileron and the CONM1 and CELAS2 Bulk Data entries that represented the model's inertia and stiffness have been removed. The structural and mass data are contained in input files BAH_STRUCT.DAT (see Listing 7-3) and BAH_MASS.DAT (see Listing 7-4). The effect of structural damping, which was available in the dynamic problem, has been added via a PARAM,KDAMP,+1 entry and tabular values listed on a TABDMP1 entry. In this case, a zero value of structural damping is input for comparison with previous solutions to this problem that did not include structural damping *a priori*.

The absence of the aileron also permits a simpler aerodynamic model than in Example HA144B. The aerodynamic model is divided into six strips across the span, as shown in Figure 8-3, and divided equally into four boxes chordwise. This aerodynamic idealization, while not representative of industrial practice, is consistent with the idealization of the structure into a small number of grid points.

The new Bulk Data entries relate to the different aerodynamic idealization and the items required by the dynamic analysis, that is, structural damping, and the vibration and flutter analyses. The PARAM KDAMP and TABDMP1 entries for structural damping have been discussed above. AERO specifies the aerodynamic coordinate system CORD2R 1 with its positive x-direction streamwise, the reference semichord, sea-level density, and symmetrical motion. The DLM aerodynamics are called for on CAERO1 1001, which calls for the body entry PAERO1 1000. (This entry is required even though no fuselage effects are considered.) The CAERO1 entry also includes: the basic coordinate system for the wing geometry, four equal chordwise divisions, AEFACT 77 to specify six unequal strips, and interference group IGlD 1. The continuation entry gives the geometrical data at the root and tip of the wing.

Splines

The aerodynamic and structural grids are connected by the linear SPLlNE2 along the 35% chord elastic axis, which connects to all of the aerodynamic boxes outboard of the root strip, that is, boxes 1005 through 1024. The spline is not connected to the root strip (boxes 1001 through 1004) since no motion of the fuselage is assumed, but the spline does go through all 11 structural grid points via SET1 14. The spline coordinate system CID is also the basic system because all geometry has been expressed relative to the elastic axis. The SPLlNE2 continuation entry sets DTHX = DTHY = -1.0 because there are no rotational degrees of freedom in the GENEL structural model. The aerodynamic and spline data are contained in the file BAH_AERO5.DAT and are shown in Listing 8-4.

The vibration analysis uses EIGR 10, which requests the Modified Givens method to obtain all 10 modes normalized on the maximum deflection.

Flutter Bulk Data Entries

The modal flutter analysis requires a number of generalized aerodynamic influence coefficient matrices. These are obtained for the (m, k) pairs on the MKAERO1 entry. A Mach number of 0.0 and a reduced frequency range from 0.001 to 1.0 are chosen; selection of a very low reduced frequency in the PK-method is advised if divergence is to be determined for a restrained surface or if a low frequency root, for example, the short period, is to be determined for an unrestrained vehicle. FLUTTER 40 selects the PK-method for a density ratio of 1.0 on FLFACT 1, a Mach number of 0.0 on FLFACT 2, and a series of velocities from 4800 in/s to 25,200 in/s on FLFACT 4 (flutter eigenvectors are requested on FLFACT 4 by negative velocities). Only linear interpolation on k of the (m,k) aerodynamic coefficients is allowed for the PK-method so the IMETH field is left blank, and five flutter roots are requested. The optional PARAM,LMODES entry uses all 10 vibration modes in the modal formulation so there is no problem with modal convergence when comparisons are made with earlier direct solutions. Finally, PARAM,VREF divides the solution velocities by 12.0 in/ft to output the velocities in units of ft/s. The ENDDATA entry completes the Bulk Data Section.

Case Control Commands

The Case Control Section begins with the Title, Subtitle, and Label commands. ECHO = BOTH prints both annotated and sorted Bulk Data entries. SPC = 1 points to the Bulk Data entry SPC1 1, which adds the constraints in the plunge and pitch degrees of freedom to the fuselage. METHOD = 10 points to EIGR 10 for vibration analysis and SVEC = ALL requests the print of the vibration modes of the a-set grid points. FMETHOD = 40 points to the FLUTTER 40 entry for the PK-flutter method. DISP = ALL prints all the displacements of the grid points in addition to the modal eigenvectors. The BEGIN BULK command ends the Case Control Section.

The Executive Control Section gives the identification ID MSC, HA145B. TIME 10 specifies 10.0 minutes CPU computing time. SOL 145 calls for the Aerodynamic Flutter DMAP solution sequence. The remaining statements determine the formats of the plotted output. The CEND statement is last in the Executive Control Section.

Output

The input data are shown in Listing 8-5 followed by the sorted Bulk Data entries in Listing 8-6. Selected items of the printed output are shown in Listing 8-7. The V-g and V-f curves are shown in Figure 8-4 and Figure 8-5. The significant results are discussed below.

The first output shown is the weight and balance analysis. Next, the vibration analysis gives the 10 coupled frequencies of the cantilever wing. The first two frequencies are $12.798 \text{ rad/s} = 2.037 \text{ Hz}$ for first bending and $22.322 \text{ rad/s} = 3.553 \text{ Hz}$ for first torsion. These are in close agreement with the uncoupled bending and torsion frequencies of 12.799 and 22.357 rad/s obtained in Bisplinghoff, Ashley, and Halfman (1955, pp. 177 and 181) [Reference 8]. The first five vibration modes are given next. The PK-Flutter Summaries are preceded by the flutter modal participation factors and followed by the flutter grid point modes near the flutter and divergence speeds. The Flutter Summaries for the five requested flutter modes are presented, showing a number of instabilities, including both flutter and divergence. The V-f curves are shown in Figure 8-4 and the V-g curves are shown in Figure 8-5 for the first two aeroelastic modes. The lowest flutter speed is a coupled first-bending/ first-torsion mode flutter and is found in Figure 8-5 (and in Point 2 of the printed Flutter Summary by linear interpolation) to be $1056 \text{ ft/s} = 720 \text{ mph}$. The divergence speed is found in Figure 8-5 and Point 1 of the Flutter Summary at $1651 \text{ ft/s} = 1125 \text{ mph}$. The V-f curve for the bending mode in Figure 8-4 appears to be discontinuous as the frequency approaches zero near 1430 ft/s, and this behavior is similar to that observed by Rodden and Bellinger (1982a) [Reference 44] using Strip Theory. However, a refined analysis in the range of velocities from 1420 to 1430 ft/s shows a continuous variation in the eigenvalue as it transitions from complex to real. There is no appearance of an aerodynamic lag root. Note in Figure 8-5 that the definition of damping changes between the low speed branch, with its finite frequency, and the high speed branch, with its zero frequency. For complex roots the frequency and damping are derived from the relations following (2-172) while for real roots the damping is computed using (2-176).

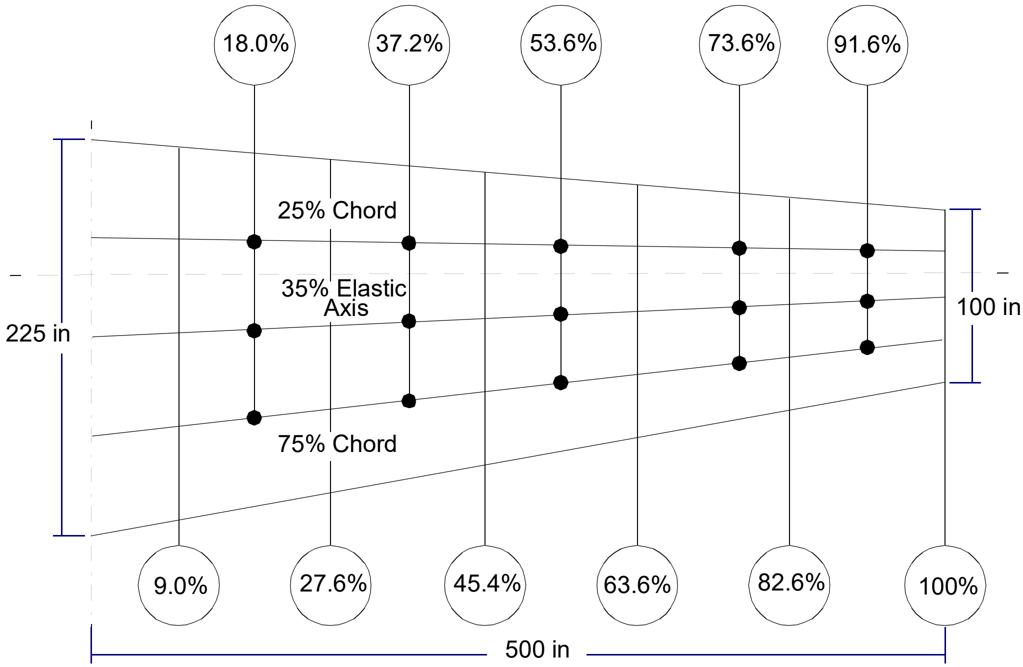

Figure 8-3 BAH Wing Planform and Aerodynamic Strip Idealization

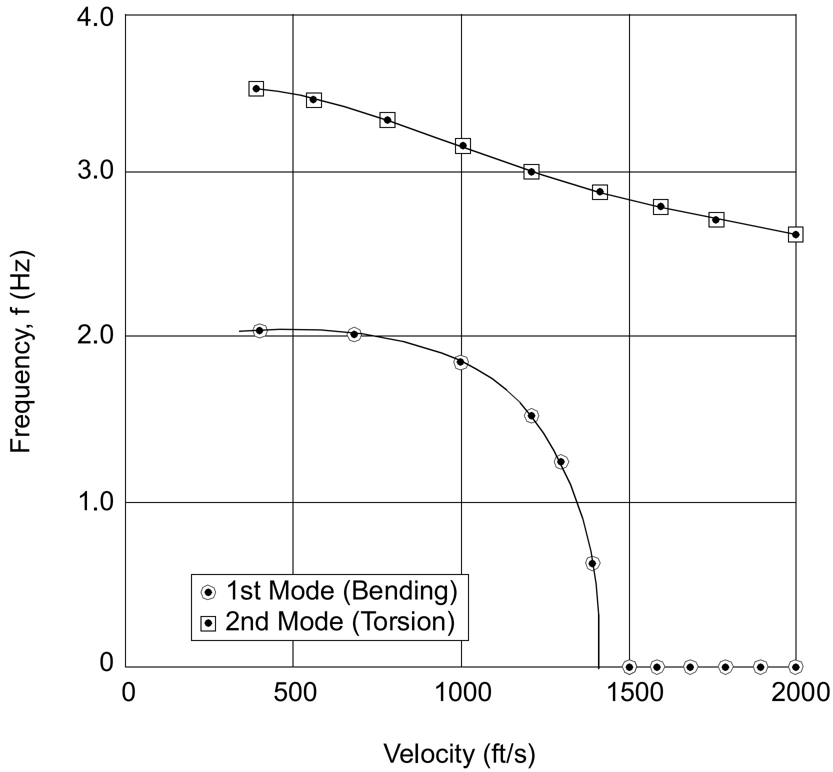

Figure 8-4 V-f Curve for BAH Wing

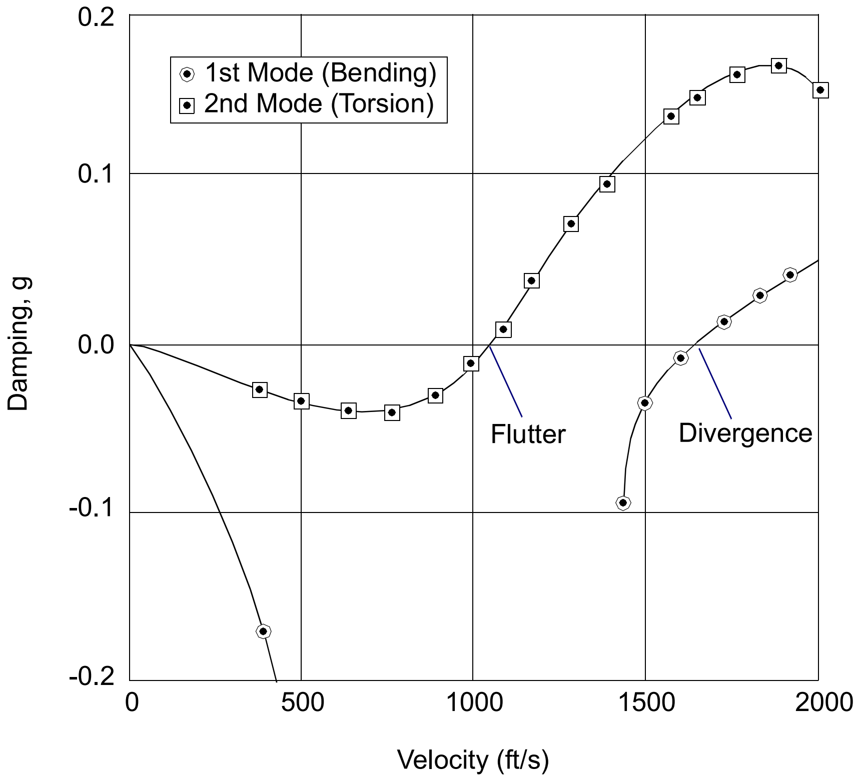

Figure 8-5 V-g Curve for BAH Wing

Listing 8-4 Input File BAH_AERO5.DAT

```
$       THIS CORD2R ENTRY DEFINES THE AERO COORDINATE SYSTEM            $
$       FLAGGED BY THE AERO ENTRY.  LISTED ARE THE ORIGIN, A            $
$       POINT ALONG THE Z AXIS AND A POINT IN THE X-Z PLANE,            $
$       ALL IN THE RID COORDINATE SYSTEM.  NOTE THAT IN THIS            $
$       COORDINATE SYSTEM THE UPSIDE DOWN AND BACKWARDS STRUC-          $
$       TURE WILL FLY UPSIDE UP AND FORWARD.                            $
$                                                                       $
$       CID     RID     A1      A2      A3      B1      B2      B3
CORD2R  1               0.      0.      0.      0.      0.      -1.     +C1
$       C1      C2      C3
+C1     -1.     0.      0.
$
$       THE CAERO1 ENTRY IS USED FOR DOUBLET-LATTICE AERODYNAMICS.      $
$       LISTED ARE ITS PAERO ENTRY ID AND THE COORDINATE SYSTEM         $
$       FOR LOCATING THE INBOARD AND OUTBOARD LEADING EDGE POINTS       $
$       (1 AND 4).  NSPAN AND NCHORD, OR LSPAN AND LCHORD, ARE          $
$       USED TO PARTITION THE WING INTO AERODYNAMIC BOXES, THE          $
$       FORMER FOR UNIFORMLY SPACED BOXES AND THE LATTER FOR            $
$       NON-UNIFORMLY SPACED BOXES.  IGID IS THE ID OF ITS              $
$       ASSOCIATED INTERFERENCE GROUP.  THE CONTINUATION ENTRY          $
$       DEFINES POINTS 1 AND 2, THE ROOT CHORD AND THE TIP CHORD.       $
$       THE BOXES FORMED BY THE GRID LINES WILL BE NUMBERED             $
$       BEGINNING WITH EID, SO A NUMBER SHOULD BE CHOSEN THAT IS        $
$       UNIQUE, AND IS GREATER THAN ALL STRUCTURAL GRID, SCALAR         $
$       AND EXTRA POINT IDS.                                            $
$                                                                       $
$       EID     PID     CP      NSPAN   NCHORD  LSPAN   LCHORD  IGID    +CA
CAERO1  1001    1000    0               4       77              1       +CA1
$       (FWD INBOARD POINT)   ROOTCHORD  (FWD OUTBOARD POINT) TIP CHORD
+CA1    78.75   0.0     0.0     225.0   35.0    500.0   0.0     100.0
$                                                                       $
$       THE AEFACT ENTRY IS A UTILITY ENTRY USED TO SPECIFY LISTS OF    $
$       NUMBERS.  THE CAERO1 ENTRY IDENTIFIES THEM BY LSPAN AND LCHORD. $
$       THIS AEFACT ENTRY AND ITS CONTINUATION ENTRY CONTAIN SIX FIELDS $
$       WHICH SPECIFY THE STRIP EDGES AS FRACTIONS OF THE SPAN.         $
$                                                                       $
$       SID     D1      D2      D3      ETC
AEFACT  77      .0      .09     .276    .454    .636    .826    1.0
$                                                                       $
$       THE PAERO ENTRY IS REQUIRED EVEN THOUGH IT IT NON-FUNCTIONAL    $
$       (BECAUSE THERE ARE NO ASSOCIATED BODIES IN THIS EXAMPLE).       $
$                                                                       $
PAERO1  1000
$                                                                       $
$               * * SPLINE FIT ON THE LIFTING SURFACES * *              $
$                                                                       $
$                    * LINEAR SPLINE FIT ON THE WING *                  $
$                                                                       $
$        THE SPLINE2 ENTRY SPECIFIES A BEAM SPLINE FOR INTERPOLAT-      $
$        ION OVER THE REGION OF THE CAERO ENTRY (ID1 AND ID2 ARE        $
$        THE FIRST AND LAST BOXES IN THIS REGION).  SETG REFERS         $
$        TO A SET1 ENTRY WHERE THE STRUCTURAL GRID POINTS ARE           $
$        DEFINED.  DZ AND DTOR ARE SMOOTHING CONSTANTS FOR LINEAR       $
$        ATTACHMENT AND TORSIONAL FLEXIBILITIES.  DTHX AND DTHY         $
$        ARE ROTATIONAL ATTACHMENT FLEXIBILITIES. CID IDENTIFIES        $
$        THE SPLINE AXIS.                                               $
$                                                                       $
$       EID     CAERO   ID1     ID2     SETG    DZ      DTOR    CID
SPLINE2 100     1001    1005    1024    14      0.0     1.0     0       +SP100
$       DTHX    DTHY
+SP100  -1.0    -1.0
$                                                                       $
$        THE SET1 ENTRY DEFINES THE SETS OF STRUCTURAL GRID POINTS      $
$        TO BE USED BY THE BEAM SPLINE FOR INTERPOLATION.               $
$                                                                       $
$       SID     G1      G2      G3      G4      G5      G6
SET1    14      1       THRU    11
```

Listing 8-5 Input Files for Jet Transport Wing by Lifting Surface Theory

```
        N A S T R A N    E X E C U T I V E    C O N T R O L    D E C K    E C H O


ID MSC, HA145B
$$$$$$$$    HANDBOOK FOR AEROELASTIC ANALYSIS EXAMPLE HA145B    $$$$$$$$
$                                                                      $
$       MODEL DESCRIPTION       BAH JET TRANSPORT WING EXAMPLE         $
$                               CANTILEVERED WING WITH TEN BEAM        $
$                               ELEMENTS AND DUMBBELL MASSES           $
$                                                                      $
$       SOLUTION                PK FLUTTER ANALYSIS METHOD USING       $
$                               DOUBLET-LATTICE AERODYNAMICS AT        $
$                               MACH NO. 0.0                           $
$                                                                      $
$                                                                      $
$       OUTPUT                  TABULATED MODAL DEFLECTIONS PLUS       $
$                               X-Y PLOTS OF V-G FLUTTER DATA          $
$                                                                      $
$$$$$$$$                                                        $$$$$$$$
TIME 10 $ TIME IN CPU MINUTES
SOL 145  $ FLUTTER ANALYSIS
CEND
```

```
EXAMPLE HA145B: BAH JET TRANSPORT WING FLUTTER ANALYSIS                     PAGE     2
 CANTILEVERED, DOUBLET-LATTICE AERODYNAMICS AT MACH NO. 0.0
 PK FLUTTER METHOD
                                 C A S E    C O N T R O L    D E C K    E C H O
            CARD
            COUNT
             1      TITLE = EXAMPLE HA145B: BAH JET TRANSPORT WING FLUTTER ANALYSIS
             2      SUBTI = CANTILEVERED, DOUBLET-LATTICE AERODYNAMICS AT MACH NO. 0.0
             3      LABEL = PK FLUTTER METHOD
             4        ECHO    = BOTH
             5        SPC     = 1    $ FUSELAGE CONSTRAINT
             6        SDAMP   = 2000 $ STRUCTURAL DAMPING
             7        METHOD  = 10   $ MODIFIED GIVENS FOR VIBRATION ANALYSIS
             8        SVEC    = ALL $ PRINT VIBRATION MODES
             9        FMETHOD = 40   $ PK-FLUTTER METHOD
            10        DISP    = ALL $ PRINT FLUTTER MODES
            11      OUTPUT(XYOUT)
            12        CSCALE 2.0
            13        PLOTTER NASTRAN
            14        CURVELINESYMBOL = -6
            15        YTTITLE = DAMPING  G
            16        YBTITLE =FREQUENCY  F HZ
            17        XTITLE  = VELOCITY  V (FT/SEC)
            18        XMIN  =     0.
            19        XMAX  = 2500.
            20        YTMIN =  -.6
            21        YTMAX =  +.1
            22        YBMIN =   0.
            23        YBMAX =  15.
            24        XTGRID LINES = YES
            25        XBGRID LINES = YES
            26        YTGRID LINES = YES
            27        YBGRID LINES = YES
            28        UPPER TICS  = -1
            29        TRIGHT TICS = -1
            30        BRIGHT TICS = -1
            31        XYPLOT VG / 1(G,F) 2(G,F) 3(G,F) 4(G,F) 5(G,F)
            32        CURVELINESYMBOL = -6
            33        YTTITLE = DAMPING  G
            34        YBTITLE =FREQUENCY  F HZ
            35        XTITLE  = VELOCITY  V (FT/SEC)
            36        XMIN  =     0.
            37        XMAX  = 1600.
            38        YTMIN =  -1.7
            39        YTMAX =   +.1
            40        YBMIN =   0.
            41        YBMAX =   2.5
            42        XTGRID LINES = YES
            43        XBGRID LINES = YES
            44        YTGRID LINES = YES
            45        YBGRID LINES = YES
            46        UPPER TICS   = -1
            47        TRIGHT TICS  = -1
            48        BRIGHT TICS  = -1
            49        XYPLOT VG / 1(G,F)
            50      BEGIN BULK
```

Listing 8-5 Input Files for Jet Transport Wing by Lifting Surface Theory (Continued)

```
EXAMPLE HA145B: BAH JET TRANSPORT WING FLUTTER ANALYSIS                     PAGE     4
 CANTILEVERED, DOUBLET-LATTICE AERODYNAMICS AT MACH NO. 0.0
 PK FLUTTER METHOD
                                I N P U T   B U L K   D A T A   D E C K   E C H O

                        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                        $*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
                        $                                                                    $
                        $        THE ANNOTATIONS IN THIS INPUT DECK ARE INTENDED TO          $
                        $        EXPLAIN THE DATA ON THE CARD IMAGES FOR THIS SPECIFIC       $
                        $        EXAMPLE WITHOUT REFERENCE TO THE VARIOUS MANUALS WHERE      $
                        $        MORE GENERAL DESCRIPTIONS WILL BE FOUND.                    $
                        $                                                                    $
                        $*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
                        INCLUDE BAH_STRUCT.DAT
                        $
                        INCLUDE BAH_MASS.DAT
                        $                                                                    $
                        $                  * * STRUCTURAL CONSTRAINTS * *                    $
                        $                                                                    $
                        $        THE SPC1 ENTRY CONSTRAINS DOFS OF THE LISTED GRID POINTS.   $
                        $                                                                    $
                        $       SID     C       G1      G2      ETC.
                        SPC1    1       345     11
                        $                                                                    $
                        $                   * * STRUCTURAL DAMPING * *                       $
                        $                                                                    $
                        $        THE PARAMETER KDAMP DETERMINES THE MANNER OF INCLUSION      $
                        $        OF STRUCTURAL DAMPING IN EQUATIONS OF MOTION (SEE HANDBOOK  $
                        $        FOR DYNAMIC ANALYSIS, SECT. 3.2.2).  IF SET TO -1, MODAL    $
                        $        DAMPING IS PUT INTO COMPLEX STIFFNESS MATRIX AS STRUCTURAL  $
                        $        DAMPING.                                                    $
                        $                                                                    $
                        $       N       V1      V2
                        PARAM   KDAMP   +1
                        $                                                                    $
                        $        THE TABDMP1 ENTRY DEFINES MODAL DAMPING AS A TABULAR        $
                        $        FUNCTION OF FREQUENCY.  THE DAMPING LEVELS ARE LINEAR       $
                        $        BETWEEN THE FREQUENCY AND DAMPING PAIRS AND ARE ZERO        $
                        $        OUTSIDE THE TABULATED FREQUENCY RANGE.                      $
                        $                                                                    $
                        $       ID                                                           +TDP
                        TABDMP1 2000                                                         +T2000
                        $       F1      G1      F2      G2      ETC             ENDT
                        +T2000  0.0     0.0     10.0    0.0     ENDT
                        $                                                                    $
                        $                                                                    $
                        $                       * * * AERODYNAMIC DATA * * *                 $
                        $                                                                    $
                        $                           (SNAIL-IN-SEC SYSTEM)                    $
                        $                                                                    $
                        $                         * * ELEMENT GEOMETRY * *                   $
                        $                                                                    $
                        $        THE AERO ENTRY SPECIFIES THE AERO COORDINATE SYSTEM, THE    $
                        $        VELOCITY (USED FOR DATA RECOVERY), THE REFERENCE CHORD      $
                        $        AND FLUID DENSITY, PLUS SYMMETRY KEYS.  SYMXZ=1 INDICATES   $
                        $        THAT THE MODEL IS MOUNTED WITH A ROOT REFLECTION PLANE;     $
                        $        SYMXY = 0 INDICATES THAT THE MODEL IS MOUNTED FAR ENOUGH    $
                        $        FROM THE FLOOR SO THAT REFLECTION EFFECTS ARE NEGLIGIBLE.   $
                        $                                                                    $
                        $       ACSID   VELOCITY REFC   RHOREF  SYMXZ   SYMXY
                        AERO    1               131.232 1.1468-7  1
                        $                                                                    $
                        INCLUDE BAH_AERO5.DAT
                        $                                                                    $
                        $                  * * * SOLUTION SPECIFICATIONS * * *               $
                        $                                                                    $
                        $                   * VIBRATION SOLUTION PARAMETERS *                $
                        $                                                                    $
                        $        THE EIGR ENTRY SPECIFIES THE METHOD OF EXTRACTING THE EIGEN-  $
                        $        SOLUTIONS OF THE STRUCTURE IN A VACUUM, IN THIS CASE THE    $
                        $        MODIFIED GIVENS METHOD.  TEN MODES ARE DESIRED, NORMALIZED  $
                        $        ON THE MAXIMUM DISPLACEMENTS.                               $
```

Listing 8-5 Input Files for Jet Transport Wing by Lifting Surface Theory (Continued)

```
$                                                                       $
$       SID     METHOD  F1      F2              ND                      $
EIGR    10      MGIV                            10                      +EIGR
$       NORM    G       C                                               $
+EIGR   MAX
$                                                                       $
$                       * AERODYNAMIC CONDITIONS *                      $
$                                                                       $
$        ALL COMBINATIONS OF MACH NUMBER AND REDUCED FREQUENCY LISTED   $
$        ON THE MKAERO1 ENTRY AND ITS CONTINUATION ENTRY WILL BE USED   $
$        TO GENERATE GENERALIZED AERO FORCE MATRICES.  IF MORE THAN     $
$        EIGHT MACH NO.S OR REDUCED FREQUENCIES ARE REQUIRED A SECOND   $
$        MKAERO1 ENTRY IS NECESSARY.                                    $
$                                                                       $
$        M1     M2      M3      ETC
MKAERO1 0.                                                              +MK
$        K1     K2      K3      K4      K5      ETC
+MK     0.001   0.05    0.10    0.20    0.50    1.0
$                                                                       $
$                      *FLUTTER SOLUTION PARAMETERS *                   $
$                                                                       $
$        THE FLUTTER ENTRY DEFINES THE METHOD OF SOLUTION, IDENTIFIES   $
$        THE FLFACT ENTRIES THAT FOLL0W, SPECIFIES THE INTERPOLATION    $
$        METHOD, THE NUMBER OF ROOTS DESIRED IN THE OUTPUT AND THE      $
$        CRITERION FOR CONVERGENCE (DEFAULT IS 10-3).                   $
$                                                                       $
$       SID     METHOD  DENS    MACH    VEL     IMETH   NVALUE  EPS     $
FLUTTER 40      PK      1       2       4       L       5
$                                                                       $
$        FLFACT ENTRIES ARE USED TO SPECIFY DENSITY RATIOS, MACH NO.S   $
$        AND REDUCED FREQUENCIES/VELOCITIES FOR FLUTTER ANALYSES.       $
$        NEGATIVE VELOCITIES ARE SIGNALS TO COMPUTE AND PRINT EIGEN-    $
$        VECTORS.                                                       $
$                                                                       $
$       SID     F1      F2      F3      F4      F5      F6      F7      $
FLFACT  1       1.                                                      DENSITY
FLFACT  2       .0                                                      MACH NO
FLFACT  4       4800.   6000.   7200.   8400.   9600.   10800.  -12000. +FLF4
+FLF4   -13200. 14400.  15600.  16800.  16920.  17040.  17100.  17112.  +FLF4A
+FLF4A  17124.  17136.  17148.  17160.  18000.  -19200. -20400. 21600.  +FLF4B
+FLF4B  22800.  24000.  25200.                                          VELOCITY
$                                                                       $
$        THE PARAM,LMODES,N ENTRY SPECIFIES THAT N MODES ARE TO BE      $
$        USED IN THE FLUTTER ANALYSIS.                                  $
$                                                                       $
PARAM   LMODES  10
$                                                                       $
$        THE PARAM,VREF,C ENTRY SPECIFIES A CONVERSION FACTOR TO BE     $
$        USED TO CONVERT THE DIMENSIONS OF THE OUTPUT VELOCITIES BY     $
$        DIVIDING BY C, IN THIS CASE BY 12.0 IN/FT TO PRINT VEL-        $
$        OCITIES IN FT/SEC RATHER THAN IN/SEC.                          $
$                                                                       $
PARAM   VREF    12.0
$
ENDDATA

INPUT BULK DATA CARD COUNT =      333
```

Listing 8-6 Sorted Bulk Data Entries for Jet Transport Wing by Lifting Surface Theory

```
EXAMPLE HA145B: BAH JET TRANSPORT WING FLUTTER ANALYSIS                                                       PAGE    11
 CANTILEVERED, DOUBLET-LATTICE AERODYNAMICS AT MACH NO. 0.0
 PK FLUTTER METHOD
                                                    S O R T E D   B U L K   D A T A   E C H O
            CARD
            COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
               1-        AEFACT  77      .0      .09     .276    .454    .636    .826    1.0
               2-        AERO    1               131.232 1.1468-71
               3-        CAERO1  1001    1000    0               4       77              1       +CA1
               4-        +CA1    78.75   0.0     0.0     225.0   35.0    500.0   0.0     100.0
               5-        CMASS2  121     5248.7  1       3
               6-        CMASS2  122     134.9   1       3       2       3
               7-        CMASS2  123     790.3   2       3
               8-        CMASS2  341     9727.   3       3
               9-        CMASS2  342     11005.  3       3       4       3
              10-        CMASS2  343     473.    4       3
              11-        CMASS2  561     3253.6  5       3
              12-        CMASS2  562     -139.7  5       3       6       3
              13-        CMASS2  563     946.3   6       3
              14-        CMASS2  781     2617.8  7       3
              15-        CMASS2  782     21.     7       3       8       3
              16-        CMASS2  783     782.3   8       3
              17-        CMASS2  9101    494.8   9       3
              18-        CMASS2  9102    -7.3    9       3       10      3
              19-        CMASS2  9103    185.2   10      3
              20-        CONM1   1       11                                                      +51
              21-        +51     17400.                          4.37+7                          +52
              22-        +52             4.35+09
              23-        CORD2R  1               0.      0.      0.      0.      0.      -1.     +C1
              24-        +C1     -1.     0.      0.
              25-        EIGR    10      MGIV                            10                      +EIGR
              26-        +EIGR   MAX
              27-        FLFACT  1       1.                                                      DENSITY
              28-        FLFACT  2       .0                                                      MACH NO
              29-        FLFACT  4       4800.   6000.   7200.   8400.   9600.   10800.  -12000. +FLF4
              30-        +FLF4   -13200. 14400.  15600.  16800.  16920.  17040.  17100.  17112.  +FLF4A
              31-        +FLF4A  17124.  17136.  17148.  17160.  18000.  -19200. -20400. 21600.  +FLF4B
              32-        +FLF4B  22800.  24000.  25200.                                          VELOCITY
              33-        FLUTTER 40      PK      1       2       4       L       5
              34-        GENEL   432             1       3       2       3       3       3       +01
              35-        +01     4       3       5       3       6       3       7       3       +02
              36-        +02     8       3       9       3       10      3                       +03
              37-        +03     UD              11      3       11      4       11      5       +04
              38-        +04     11      6                                                       +05
              39-        +05     Z       8.7172-61.3361-61.2778-56.2720-61.6251-51.0492-52.0478-5+06
              40-        +06     1.5630-52.4285-52.0403-53.0861-56.2720-63.2297-51.0492-53.3529-5+07
              41-        +07     1.5630-53.5021-52.0257-53.5785-52.7732-51.5726-54.8255-53.7628-5+08
              42-        +08     7.3284-56.4338-59.5810-58.8378-56.3749-53.7628-58.0136-56.4338-5+09
              43-        +09     1.0012-48.8378-51.1811-41.2758-41.1344-41.9350-41.8160-42.5283-4+10
              44-        +10     2.4294-41.6999-41.8160-42.2920-42.4294-42.8249-43.6862-43.5052-4+11
              45-        +11     5.2675-45.1171-44.2292-45.1171-45.7187-48.4840-48.2340-49.2340-4+12
              46-        +12     S       1.0     90.0    -20.25  45.0    1.0     90.0    81.0    +13
              47-        +13     45.0    1.0     186.0   -17.85  141.0   1.0     186.0   71.4    +14
              48-        +14     141.0   1.0     268.0   -15.80  223.0   1.0     268.0   63.2    +15
              49-        +15     223.0   1.0     368.0   -13.30  323.0   1.0     368.0   53.2    +16
              50-        +16     323.0   1.0     458.0   -11.05  413.0   1.0     458.0   44.2    +17
              51-        +17     413.0
              52-        GRID    1               20.25   90.                     12456
              53-        GRID    2               -81.    90.                     12456
              54-        GRID    3               17.85   186.                    12456
              55-        GRID    4               -71.4   186.                    12456
              56-        GRID    5               15.8    268.                    12456
              57-        GRID    6               -63.2   268.                    12456
              58-        GRID    7               13.3    368.                    12456
              59-        GRID    8               -53.2   368.                    12456
              60-        GRID    9               11.05   458.                    12456
              61-        GRID    10              -44.2   458.                    12456
              62-        GRID    11              0.0     0.                      126
              63-        MKAERO1 0.                                                              +MK
              64-        +MK     0.001   0.05    0.10    0.20    0.50    1.0
              65-        PAERO1  1000
              66-        PARAM   GRDPNT  11
              67-        PARAM   KDAMP   -1
              68-        PARAM   LMODES  10
              69-        PARAM   VREF    12.0
              70-        PARAM   WTMASS  .0025907
              71-        SET1    14      1       THRU    11
              72-        SPC1    1       345     11
              73-        SPLINE2 100     1001    1005    1024    14      0.0     1.0     0       +SP100
              74-        +SP100  -1.0    -1.0
              75-        TABDMP1 2000                                                            +T2000
              76-        +T2000  0.0     0.0     10.0    0.0     ENDT
                         ENDDATA
                 TOTAL COUNT=        77
```

Listing 8-7 Output for Jet Transport Wing by Lifting Surface Theory

```
EXAMPLE HA145B: BAH JET TRANSPORT WING FLUTTER ANALYSIS                                                      PAGE    14
 CANTILEVERED, DOUBLET-LATTICE AERODYNAMICS AT MACH NO. 0.0

 PK FLUTTER METHOD
                     O U T P U T   F R O M   G R I D   P O I N T   W E I G H T   G E N E R A T O R

                                           REFERENCE POINT =       11
                                                         M O
                 *  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00 *
                 *  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00 *
                 *  0.000000E+00  0.000000E+00  4.191900E+04  5.128960E+06 -1.642074E+05  0.000000E+00 *
                 *  0.000000E+00  0.000000E+00  5.128960E+06  1.350243E+09 -2.381847E+07  0.000000E+00 *
                 *  0.000000E+00  0.000000E+00 -1.642074E+05 -2.381847E+07  4.458782E+09  0.000000E+00 *
                 *  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00 *
                                                          S
                                    *  1.000000E+00  0.000000E+00  0.000000E+00 *
                                    *  0.000000E+00  1.000000E+00  0.000000E+00 *
                                    *  0.000000E+00  0.000000E+00  1.000000E+00 *
                         DIRECTION
                    MASS AXIS SYSTEM (S)     MASS              X-C.G.        Y-C.G.        Z-C.G.
                            X             0.000000E+00      0.000000E+00  0.000000E+00  0.000000E+00
                            Y             0.000000E+00      0.000000E+00  0.000000E+00  0.000000E+00
                            Z             4.191900E+04      3.917256E+00  1.223541E+02  0.000000E+00
                                                         I(S)
                                    *  7.226942E+08  3.727022E+06  0.000000E+00 *
                                    *  3.727022E+06  4.458139E+09  0.000000E+00 *
                                    *  0.000000E+00  0.000000E+00  0.000000E+00 *
                                                         I(Q)
                                    *  4.458143E+09                             *
                                    *                7.226906E+08               *
                                    *                              0.000000E+00 *
                                                          Q
                                    *  9.977437E-04  9.999995E-01  0.000000E+00 *
                                    * -9.999995E-01  9.977437E-04  0.000000E+00 *
                                    *  0.000000E+00  0.000000E+00  1.000000E+00 *

                                          R E A L   E I G E N V A L U E S
    MODE    EXTRACTION      EIGENVALUE            RADIANS             CYCLES            GENERALIZED         GENERALIZED
     NO.       ORDER                                                                        MASS              STIFFNESS
      1          1        1.637768E+02        1.279753E+01        2.036790E+00        8.160930E+00        1.336571E+03
      2          2        4.982469E+02        2.232145E+01        3.552568E+00        5.525822E+01        2.753224E+04
      3          3        2.092550E+03        4.574440E+01        7.280447E+00        7.079897E+00        1.481504E+04
      4          4        5.402874E+03        7.350424E+01        1.169856E+01        8.652712E+00        4.674951E+04
      5          5        8.742090E+03        9.349915E+01        1.488085E+01        4.002357E+00        3.498896E+04
      6          8        1.766007E+04        1.328912E+02        2.115029E+01        3.883447E+00        6.858195E+04
      7          6        2.398459E+04        1.548696E+02        2.464826E+01        3.597392E+00        8.628196E+04
      8         10        4.211864E+04        2.052283E+02        3.266309E+01        3.142601E+00        1.323621E+05
      9          9        6.020812E+04        2.453734E+02        3.905239E+01        1.016253E+00        6.118669E+04
     10          7        9.183204E+04        3.030380E+02        4.823000E+01        8.617019E+00        7.913184E+05

 EIGENVALUE =  1.637768E+02
     CYCLES =  2.036790E+00         R E A L   E I G E N V E C T O R   N O .         1

 POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
        1      G                                     4.518474E-02
        2      G                                     4.250221E-02
        3      G                                     1.482559E-01
        4      G                                     1.437271E-01
        5      G                                     3.794104E-01
        6      G                                     3.767312E-01
        7      G                                     6.929946E-01
        8      G                                     6.926546E-01
        9      G                                     9.989689E-01
       10      G                                     1.000000E+00

 EIGENVALUE =  4.982469E+02
     CYCLES =  3.552568E+00         R E A L   E I G E N V E C T O R   N O .         2

 POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
        1      G                                    -1.635563E-01
        2      G                                     5.449901E-01
        3      G                                    -2.796319E-01
        4      G                                     1.000000E+00
        5      G                                    -2.267440E-01
        6      G                                     9.465655E-01
        7      G                                    -1.388892E-01
        8      G                                     8.878612E-01
        9      G                                    -3.973597E-02
       10      G                                     8.224477E-01
```

Listing 8-7 Output for Jet Transport Wing by Lifting Surface Theory (Continued)

```
 EIGENVALUE =  2.092550E+03
     CYCLES =  7.280447E+00        R E A L   E I G E N V E C T O R   N O .          3

  POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
        1      G                                     -2.196879E-01
        2      G                                     -2.438909E-01
        3      G                                     -3.054668E-01
        4      G                                     -3.628896E-01
        5      G                                     -3.718194E-01
        6      G                                     -4.285979E-01
        7      G                                      2.038223E-01
        8      G                                      1.633554E-01
        9      G                                      1.000000E+00
       10      G                                      9.818934E-01

 EIGENVALUE =  5.402874E+03
     CYCLES =  1.169856E+01        R E A L   E I G E N V E C T O R   N O .          4

 POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
        1      G                                      2.913901E-01
        2      G                                      2.796087E-01
        3      G                                      3.067727E-01
        4      G                                      3.535685E-01
        5      G                                     -5.594192E-01
        6      G                                     -4.900773E-01
        7      G                                     -1.464054E-01
        8      G                                     -2.030947E-02
        9      G                                      8.377002E-01
       10      G                                      1.000000E+00

 EIGENVALUE =  8.742090E+03
     CYCLES =  1.488085E+01        R E A L   E I G E N V E C T O R   N O .          5

 POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
        1      G                                     -1.906066E-04
        2      G                                     -7.756479E-02
        3      G                                     -4.789248E-03
        4      G                                     -9.476011E-02
        5      G                                     -9.394086E-02
        6      G                                      4.210923E-01
        7      G                                     -3.057272E-01
        8      G                                      1.000000E+00
        9      G                                     -3.756571E-01
       10      G                                      9.481917E-01

                                                EIGENVECTOR FROM THE PK METHOD
   EIGENVALUE =    -1.31927E-01    1.96569E+01
   EIGENVECTOR
               1.00000E+00    0.00000E+00
               1.13370E-01   -6.91265E-02
              -6.34859E-03   -2.10305E-02
              -8.14869E-03   -7.97172E-04
               1.99117E-02   -3.57499E-03
              -5.61990E-03   -9.72727E-04
               1.38024E-03   -1.52440E-03
               7.52492E-04    7.81682E-04
               4.24761E-03   -1.17154E-04
              -3.95885E-04    7.67171E-05

                                                EIGENVECTOR FROM THE PK METHOD
   EIGENVALUE =     1.01338E-01    1.92174E+01
   EIGENVECTOR
               1.00000E+00    0.00000E+00
               8.18942E-02   -6.34056E-02
              -8.22495E-03   -2.27926E-02
              -7.60734E-03   -4.07515E-04
               1.82604E-02   -3.33487E-03
              -5.27874E-03   -8.20808E-04
               1.16707E-03   -1.45133E-03
               7.91223E-04    7.91778E-04
               3.96970E-03   -6.62259E-05
              -3.58191E-04    1.04548E-04
```

Listing 8-7 Output for Jet Transport Wing by Lifting Surface Theory (Continued)

```
A ZERO FREQUENCY ROOT HAS EMERGED.  WHEN THE MACH NO., DENSITY AND VELOCITY ARE COMPATIBLE
IT MAY BE INTERPRETED TWO WAYS DEPENDING ON THE SIGN OF THE REAL PART:
  1. (-) A MODE IS CRITICALLY DAMPED, OR,
  2. (+) THE SYSTEM IS DIVERGING.
ONLY THE MOST CRITICAL ( that is, MOST POSITIVE REAL ROOTS )  ARE PRINTED IN THE FLUTTER SUMMARY.
FOR INFORMATIONAL PURPOSES, THE REMAINING REAL ROOTS ARE PRINTED HERE.

LESS CRITICAL REAL ROOTS FOR LOOP   19       MACH         VELOCITY        DENSITY
                                        0.00000E+00    1.71600E+04    1.00000E+00
   KFREQ          DAMPING                  COMPLEX EIGENVALUE
  0.0000     -1.0980374E-01       -9.9521217E+00        0.0000000E+00
  0.0000     -9.3707547E-02       -8.4932337E+00        0.0000000E+00

LESS CRITICAL REAL ROOTS FOR LOOP   20       MACH         VELOCITY        DENSITY
                                        0.00000E+00    1.80000E+04    1.00000E+00
   KFREQ          DAMPING                  COMPLEX EIGENVALUE
  0.0000     -1.7721196E-01       -1.6847939E+01        0.0000000E+00
  0.0000     -3.9179351E-02       -3.7248688E+00        0.0000000E+00

                                         EIGENVECTOR FROM THE PK METHOD
  EIGENVALUE =    -1.00246E+00    0.00000E+00
  EIGENVECTOR
              1.00000E+00    0.00000E+00
             -1.93432E-02    0.00000E+00
              1.25923E-02    0.00000E+00
              5.83946E-03    0.00000E+00
             -1.55428E-02    0.00000E+00
              4.48947E-03    0.00000E+00
             -1.11579E-03    0.00000E+00
             -8.13973E-04    0.00000E+00
             -3.60419E-03    0.00000E+00
              2.51953E-04    0.00000E+00

                                              EIGENVECTOR FROM THE PK METHOD
  EIGENVALUE =     1.02447E+00    0.00000E+00
  EIGENVECTOR
              1.00000E+00    0.00000E+00
             -1.93953E-02    0.00000E+00
              1.07119E-02    0.00000E+00
              5.81710E-03    0.00000E+00
             -1.51907E-02    0.00000E+00
              4.39807E-03    0.00000E+00
             -1.15492E-03    0.00000E+00
             -7.33074E-04    0.00000E+00
             -3.48011E-03    0.00000E+00
              2.62640E-04    0.00000E+00

                                                      FLUTTER  SUMMARY
 POINT =    1     MACH NUMBER =  0.0000     DENSITY RATIO =  1.0000E+00     METHOD = PK

  KFREQ          1./KFREQ        VELOCITY          DAMPING        FREQUENCY          COMPLEX   EIGENVALUE
  0.1737      5.7573352E+00   4.0000000E+02   -1.7215297E-01   2.0222278E+00   -1.0936906E+00    1.2706033E+01
  0.1387      7.2089267E+00   5.0000000E+02   -2.2807270E-01   2.0187895E+00   -1.4464860E+00    1.2684429E+01
  0.1152      8.6812620E+00   6.0000000E+02   -2.9225904E-01   2.0116851E+00   -1.8470465E+00    1.2639791E+01
  0.0981      1.0193741E+01   7.0000000E+02   -3.6837316E-01   1.9987390E+00   -2.3130975E+00    1.2558448E+01
  0.0849      1.1784474E+01   8.0000000E+02   -4.6180311E-01   1.9759294E+00   -2.8666730E+00    1.2415131E+01
  0.0739      1.3524364E+01   9.0000000E+02   -5.7986718E-01   1.9369451E+00   -3.5285454E+00    1.2170185E+01
  0.0642      1.5566833E+01   1.0000000E+03   -7.3513758E-01   1.8697836E+00   -4.3182707E+00    1.1748198E+01
  0.0549      1.8206732E+01   1.1000000E+03   -9.4788873E-01   1.7585402E+00   -5.2367225E+00    1.1049234E+01
  0.0452      2.2124870E+01   1.2000000E+03   -1.2661015E+00   1.5786728E+00   -6.2792897E+00    9.9190941E+00
  0.0338      2.9572548E+01   1.3000000E+03   -1.8537142E+00   1.2795175E+00   -7.4514174E+00    8.0394459E+00
  0.0161      6.2085567E+01   1.4000000E+03   -4.2601905E+00   6.5634024E-01   -8.7843161E+00    4.1239076E+00
  0.0131      7.6550934E+01   1.4100000E+03   -5.3009262E+00   5.3611785E-01   -8.9281588E+00    3.3685279E+00
  0.0090      1.1090582E+02   1.4200000E+03   -7.7507062E+00   3.7267104E-01   -9.0743771E+00    2.3415613E+00
  0.0060      1.6583479E+02   1.4250000E+03   -1.1643057E+01   2.5010988E-01   -9.1484547E+00    1.5714867E+00
  0.0052      1.9121582E+02   1.4260000E+03   -1.3437467E+01   2.1706378E-01   -9.1633577E+00    1.3638520E+00
  0.0043      2.3360669E+02   1.4270000E+03   -1.6431654E+01   1.7779942E-01   -9.1782846E+00    1.1171467E+00
  0.0030      3.2805820E+02   1.4280000E+03   -2.3096727E+01   1.2669776E-01   -9.1932545E+00    7.9606557E-01
  0.0005      2.1647014E+03   1.4290000E+03   -1.5254637E+02   1.9214356E-02   -9.2082605E+00    1.2072737E-01
  0.0000      9.9999996E+24   1.4300000E+03   -9.3707547E-02   0.0000000E+00   -8.4932337E+00    0.0000000E+00
  0.0000      9.9999996E+24   1.5000000E+03   -3.9179351E-02   0.0000000E+00   -3.7248688E+00    0.0000000E+00
  0.0000      9.9999996E+24   1.6000000E+03   -9.8851677E-03   0.0000000E+00   -1.0024587E+00    0.0000000E+00
  0.0000      9.9999996E+24   1.7000000E+03    9.5079672E-03   0.0000000E+00    1.0244696E+00    0.0000000E+00
  0.0000      9.9999996E+24   1.8000000E+03    2.4715576E-02   0.0000000E+00    2.8197184E+00    0.0000000E+00
  0.0000      9.9999996E+24   1.9000000E+03    3.7703570E-02   0.0000000E+00    4.5404463E+00    0.0000000E+00
  0.0000      9.9999996E+24   2.0000000E+03    4.9428467E-02   0.0000000E+00    6.2656999E+00    0.0000000E+00
  0.0000      9.9999996E+24   2.1000000E+03    6.0429081E-02   0.0000000E+00    8.0431795E+00    0.0000000E+00
```

Listing 8-7 Output for Jet Transport Wing by Lifting Surface Theory (Continued)

```
  POINT =    2    MACH NUMBER =  0.0000     DENSITY RATIO =  1.0000E+00     METHOD = PK

   KFREQ          1./KFREQ        VELOCITY         DAMPING        FREQUENCY          COMPLEX   EIGENVALUE
   0.2995      3.3390682E+00   4.0000000E+02   -2.8284783E-02   3.4867945E+00   -3.0983400E-01    2.1908176E+01
   0.2370      4.2196832E+00   5.0000000E+02   -3.4942660E-02   3.4489098E+00   -3.7860614E-01    2.1670139E+01
   0.1947      5.1352148E+00   6.0000000E+02   -4.0042900E-02   3.4008248E+00   -4.2781860E-01    2.1368013E+01
   0.1641      6.0952721E+00   7.0000000E+02   -4.2240817E-02   3.3426938E+00   -4.4358701E-01    2.1002766E+01
   0.1407      7.1085973E+00   8.0000000E+02   -3.9737049E-02   3.2756515E+00   -4.0892455E-01    2.0581526E+01
   0.1223      8.1795788E+00   9.0000000E+02   -3.0523464E-02   3.2026036E+00   -3.0710500E-01    2.0122553E+01
   0.1075      9.3037176E+00   1.0000000E+03   -1.3422978E-02   3.1284924E+00   -1.3192706E-01    1.9656898E+01
   0.0955      1.0468166E+01   1.1000000E+03    1.0546523E-02   3.0585368E+00    1.0133813E-01    1.9217354E+01
   0.0858      1.1660662E+01   1.2000000E+03    3.8356557E-02   2.9953644E+00    3.6094347E-01    1.8820431E+01
   0.0777      1.2876984E+01   1.3000000E+03    6.6786908E-02   2.9384673E+00    6.1654115E-01    1.8462934E+01
   0.0708      1.4120013E+01   1.4000000E+03    9.3580134E-02   2.8859217E+00    8.4843409E-01    1.8132782E+01
   0.0702      1.4246002E+01   1.4100000E+03    9.6109807E-02   2.8808308E+00    8.6983192E-01    1.8100794E+01
   0.0696      1.4372321E+01   1.4200000E+03    9.8607071E-02   2.8757629E+00    8.9086324E-01    1.8068953E+01
   0.0693      1.4435614E+01   1.4250000E+03    9.9844672E-02   2.8732355E+00    9.0125149E-01    1.8053072E+01
   0.0692      1.4448281E+01   1.4260000E+03    1.0009081E-01   2.8727310E+00    9.0331465E-01    1.8049902E+01
   0.0692      1.4460953E+01   1.4270000E+03    1.0033698E-01   2.8722265E+00    9.0537727E-01    1.8046732E+01
   0.0691      1.4473624E+01   1.4280000E+03    1.0058212E-01   2.8717229E+00    9.0743011E-01    1.8043568E+01
   0.0690      1.4486303E+01   1.4290000E+03    1.0082768E-01   2.8712187E+00    9.0948582E-01    1.8040400E+01
   0.0690      1.4498988E+01   1.4300000E+03    1.0107257E-01   2.8707144E+00    9.1153467E-01    1.8037231E+01
   0.0650      1.5395497E+01   1.5000000E+03    1.1726157E-01   2.8358886E+00    1.0447077E+00    1.7818415E+01
   0.0598      1.6709805E+01   1.6000000E+03    1.3682486E-01   2.7870209E+00    1.1979953E+00    1.7511370E+01
   0.0553      1.8068224E+01   1.7000000E+03    1.5135424E-01   2.7385778E+00    1.3021756E+00    1.7206993E+01
   0.0514      1.9473568E+01   1.8000000E+03    1.5982650E-01   2.6904109E+00    1.3508816E+00    1.6904350E+01
   0.0478      2.0924421E+01   1.9000000E+03    1.6107894E-01   2.6429670E+00    1.3374588E+00    1.6606253E+01
   0.0446      2.2413221E+01   2.0000000E+03    1.5391463E-01   2.5972717E+00    1.2558771E+00    1.6319139E+01
   0.0418      2.3925329E+01   2.1000000E+03    1.3731916E-01   2.5547769E+00    1.1021330E+00    1.6052137E+01

  POINT =    3    MACH NUMBER =  0.0000     DENSITY RATIO =  1.0000E+00     METHOD = PK

   KFREQ          1./KFREQ        VELOCITY         DAMPING        FREQUENCY          COMPLEX   EIGENVALUE
   0.6196      1.6140474E+00   4.0000000E+02   -2.9438451E-02   7.2133226E+00   -6.6711420E-01    4.5322643E+01
   0.4958      2.0168877E+00   5.0000000E+02   -3.7501179E-02   7.2157240E+00   -8.5010922E-01    4.5337734E+01
   0.4133      2.4198287E+00   6.0000000E+02   -4.5750387E-02   7.2170258E+00   -1.0372965E+00    4.5345913E+01
   0.3542      2.8230934E+00   7.0000000E+02   -5.4224186E-02   7.2171283E+00   -1.2294401E+00    4.5346558E+01
   0.3099      3.2268467E+00   8.0000000E+02   -6.2981464E-02   7.2161126E+00   -1.4277953E+00    4.5340176E+01
   0.2754      3.6314509E+00   9.0000000E+02   -7.2098888E-02   7.2136316E+00   -1.6339262E+00    4.5324585E+01
   0.2477      4.0371413E+00   1.0000000E+03   -8.1673540E-02   7.2097082E+00   -1.8499030E+00    4.5299934E+01
   0.2250      4.4446402E+00   1.1000000E+03   -9.1822386E-02   7.2035685E+00   -2.0780029E+00    4.5261356E+01
   0.2060      4.8549180E+00   1.2000000E+03   -1.0269001E-01   7.1943407E+00   -2.3209677E+00    4.5203377E+01
   0.1898      5.2694612E+00   1.3000000E+03   -1.1444992E-01   7.1807332E+00   -2.5818686E+00    4.5117878E+01
   0.1757      5.6908121E+00   1.4000000E+03   -1.2730074E-01   7.1605339E+00   -2.8636916E+00    4.4990963E+01
   0.1744      5.7334146E+00   1.4100000E+03   -1.2865296E-01   7.1580939E+00   -2.8931241E+00    4.4975632E+01
   0.1731      5.7761230E+00   1.4200000E+03   -1.3001817E-01   7.1555586E+00   -2.9227891E+00    4.4959702E+01
   0.1725      5.7975187E+00   1.4250000E+03   -1.3070567E-01   7.1542540E+00   -2.9377081E+00    4.4951504E+01
   0.1724      5.8018012E+00   1.4260000E+03   -1.3084354E-01   7.1539903E+00   -2.9406986E+00    4.4949848E+01
   0.1722      5.8060846E+00   1.4270000E+03   -1.3098158E-01   7.1537251E+00   -2.9436920E+00    4.4948181E+01
   0.1721      5.8103690E+00   1.4280000E+03   -1.3111976E-01   7.1534591E+00   -2.9466877E+00    4.4946510E+01
   0.1720      5.8146553E+00   1.4290000E+03   -1.3125803E-01   7.1531920E+00   -2.9496851E+00    4.4944832E+01
   0.1719      5.8189421E+00   1.4300000E+03   -1.3139643E-01   7.1529241E+00   -2.9526846E+00    4.4943150E+01
   0.1633      6.1222348E+00   1.5000000E+03   -1.4142025E-01   7.1313686E+00   -3.1683588E+00    4.4807713E+01
   0.1522      6.5698667E+00   1.6000000E+03   -1.5686841E-01   7.0885115E+00   -3.4933367E+00    4.4538433E+01
   0.1420      7.0430598E+00   1.7000000E+03   -1.7326842E-01   7.0255318E+00   -3.8242695E+00    4.4142719E+01
   0.1324      7.5554371E+00   1.8000000E+03   -1.8911731E-01   6.9343309E+00   -4.1198912E+00    4.3569687E+01
   0.1231      8.1226606E+00   1.9000000E+03   -2.0079058E-01   6.8084288E+00   -4.2947721E+00    4.2778622E+01
   0.1142      8.7541361E+00   2.0000000E+03   -2.0251060E-01   6.6497960E+00   -4.2306390E+00    4.1781902E+01
   0.1059      9.4459066E+00   2.1000000E+03   -1.8885358E-01   6.4709387E+00   -3.8392146E+00    4.0658108E+01

  POINT =    4    MACH NUMBER =  0.0000     DENSITY RATIO =  1.0000E+00     METHOD = PK

   KFREQ          1./KFREQ        VELOCITY         DAMPING        FREQUENCY          COMPLEX   EIGENVALUE
   0.9974      1.0025905E+00   4.0000000E+02   -1.3031543E-02   1.1612561E+01   -4.7541595E-01    7.2963875E+01
   0.7979      1.2532856E+00   5.0000000E+02   -1.6632434E-02   1.1612122E+01   -6.0676044E-01    7.2961113E+01
   0.6652      1.5034189E+00   6.0000000E+02   -2.0310717E-02   1.1616167E+01   -7.4120438E-01    7.2986534E+01
   0.5704      1.7530142E+00   7.0000000E+02   -2.4091350E-02   1.1622624E+01   -8.7966079E-01    7.3027107E+01
   0.4995      2.0020337E+00   8.0000000E+02   -2.8009992E-02   1.1630817E+01   -1.0234653E+00    7.3078583E+01
   0.4444      2.2503262E+00   9.0000000E+02   -3.2109644E-02   1.1640956E+01   -1.1742865E+00    7.3142288E+01
   0.4004      2.4975274E+00   1.0000000E+03   -3.6435921E-02   1.1654171E+01   -1.3340160E+00    7.3225319E+01
   0.3646      2.7427378E+00   1.1000000E+03   -4.1034564E-02   1.1673470E+01   -1.5048724E+00    7.3346581E+01
   0.3351      2.9842904E+00   1.2000000E+03   -4.5869853E-02   1.1703933E+01   -1.6865882E+00    7.3537979E+01
   0.3108      3.2177768E+00   1.3000000E+03   -5.0232433E-02   1.1759235E+01   -1.8557231E+00    7.3885460E+01
   0.2913      3.4329169E+00   1.4000000E+03   -4.6051182E-02   1.1870154E+01   -1.7173034E+00    7.4582382E+01
   0.2895      3.4541233E+00   1.4100000E+03   -4.4069543E-02   1.1881545E+01   -1.6449828E+00    7.4653954E+01
   0.2877      3.4756999E+00   1.4200000E+03   -4.1757211E-02   1.1891529E+01   -1.5599802E+00    7.4716682E+01
   0.2868      3.4866982E+00   1.4250000E+03   -4.0513523E-02   1.1895758E+01   -1.5140563E+00    7.4743256E+01
   0.2866      3.4889159E+00   1.4260000E+03   -4.0259469E-02   1.1896540E+01   -1.5046608E+00    7.4748169E+01
   0.2864      3.4911397E+00   1.4270000E+03   -4.0003765E-02   1.1897299E+01   -1.4951994E+00    7.4752937E+01
   0.2863      3.4933696E+00   1.4280000E+03   -3.9746653E-02   1.1898036E+01   -1.4856815E+00    7.4757568E+01
   0.2861      3.4956057E+00   1.4290000E+03   -3.9488193E-02   1.1898751E+01   -1.4761094E+00    7.4762062E+01
   0.2859      3.4978483E+00   1.4300000E+03   -3.9228391E-02   1.1899445E+01   -1.4664831E+00    7.4766418E+01
   0.2693      3.7128718E+00   1.5000000E+03   -1.8196461E-01   1.1759069E+01   -6.7221742E+00    7.3884415E+01
   0.2447      4.0859079E+00   1.6000000E+03   -2.0235516E-01   1.1397853E+01   -7.2458143E+00    7.1614822E+01
   0.2231      4.4824362E+00   1.7000000E+03   -2.0488223E-01   1.1038916E+01   -7.1052704E+00    6.9359558E+01
   0.2037      4.9082031E+00   1.8000000E+03   -1.8748665E-01   1.0674354E+01   -6.2872663E+00    6.7068947E+01
   0.1864      5.3653989E+00   1.9000000E+03   -1.5004404E-01   1.0307261E+01   -4.8586082E+00    6.4762428E+01
   0.1708      5.8532186E+00   2.0000000E+03   -1.0008541E-01   9.9455061E+00   -3.1271415E+00    6.2489460E+01
   0.1572      6.3628674E+00   2.1000000E+03   -4.9355671E-02   9.6063423E+00   -1.4895154E+00    6.0358429E+01
```

Listing 8-7 Output for Jet Transport Wing by Lifting Surface Theory (Continued)

```
  POINT =    5     MACH NUMBER =  0.0000     DENSITY RATIO =  1.0000E+00     METHOD = PK

   KFREQ           1./KFREQ         VELOCITY          DAMPING          FREQUENCY           COMPLEX   EIGENVALUE
   1.2569       7.9562515E-01    4.0000000E+02    -3.9658464E-02    1.4633328E+01    -1.8231772E+00     9.1943916E+01
   0.9983       1.0017462E+00    5.0000000E+02    -5.0275218E-02    1.4527937E+01    -2.2946043E+00     9.1281723E+01
   0.8247       1.2124908E+00    6.0000000E+02    -6.0894571E-02    1.4403379E+01    -2.7554522E+00     9.0499107E+01
   0.6997       1.4292080E+00    7.0000000E+02    -7.1599685E-02    1.4255886E+01    -3.2066770E+00     8.9572380E+01
   0.6048       1.6535462E+00    8.0000000E+02    -8.2352780E-02    1.4082030E+01    -3.6432874E+00     8.8480011E+01
   0.5298       1.8875158E+00    9.0000000E+02    -9.3020976E-02    1.3878532E+01    -4.0557795E+00     8.7201393E+01
   0.4687       2.1335819E+00    1.0000000E+03    -1.0342184E-01    1.3642134E+01    -4.4324565E+00     8.5716057E+01
   0.4175       2.3950694E+00    1.1000000E+03    -1.1338449E-01    1.3367993E+01    -4.7617850E+00     8.3993584E+01
   0.3736       2.6767573E+00    1.2000000E+03    -1.2273487E-01    1.3048598E+01    -5.0313172E+00     8.1986763E+01
   0.3348       2.9869835E+00    1.3000000E+03    -1.3172621E-01    1.2667829E+01    -5.2423286E+00     7.9594315E+01
   0.2992       3.3424144E+00    1.4000000E+03    -1.4796728E-01    1.2191563E+01    -5.6672840E+00     7.6601852E+01
   0.2958       3.3802135E+00    1.4100000E+03    -1.5111682E-01    1.2141340E+01    -5.7640710E+00     7.6286293E+01
   0.2926       3.4179220E+00    1.4200000E+03    -1.5454833E-01    1.2092547E+01    -5.8712697E+00     7.5979721E+01
   0.2910       3.4367015E+00    1.4250000E+03    -1.5633802E-01    1.2068816E+01    -5.9276037E+00     7.5830612E+01
   0.2907       3.4404502E+00    1.4260000E+03    -1.5670007E-01    1.2064127E+01    -5.9390225E+00     7.5801147E+01
   0.2903       3.4441965E+00    1.4270000E+03    -1.5706323E-01    1.2059456E+01    -5.9504819E+00     7.5771797E+01
   0.2900       3.4479396E+00    1.4280000E+03    -1.5742736E-01    1.2054804E+01    -5.9619761E+00     7.5742569E+01
   0.2897       3.4516809E+00    1.4290000E+03    -1.5779237E-01    1.2050172E+01    -5.9735036E+00     7.5713463E+01
   0.2894       3.4554188E+00    1.4300000E+03    -1.5815827E-01    1.2045560E+01    -5.9850640E+00     7.5684486E+01
   0.2726       3.6680081E+00    1.5000000E+03    -2.1511095E-02    1.1902894E+01    -8.0438685E-01     7.4788094E+01
   0.2540       3.9365799E+00    1.6000000E+03    -4.9833781E-03    1.1830213E+01    -1.8521078E-01     7.4331421E+01
   0.2370       4.2191119E+00    1.7000000E+03     1.6927561E-03    1.1727880E+01     6.2368281E-02     7.3688446E+01
   0.2218       4.5080471E+00    1.8000000E+03    -6.8890274E-04    1.1621861E+01    -2.5152635E-02     7.3022308E+01
   0.2086       4.7933521E+00    1.9000000E+03    -1.1143429E-02    1.1537346E+01    -4.0390077E-01     7.2491287E+01
   0.1974       5.0647664E+00    2.0000000E+03    -2.5090471E-02    1.1493762E+01    -9.0598476E-01     7.2217438E+01
   0.1878       5.3240671E+00    2.1000000E+03    -3.7430566E-02    1.1480675E+01    -1.3500308E+00     7.2135208E+01

 COMPLEX EIGENVALUE = -1.319271E-01,  1.965690E+01
                                      C O M P L E X   E I G E N V E C T O R   NO.         2
                                                         (REAL/IMAGINARY)

 POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
        1      G      0.0            0.0            2.508526E-02   0.0            0.0            0.0
                      0.0            0.0            1.613183E-02   0.0            0.0            0.0
        2      G      0.0            0.0            1.031495E-01   0.0            0.0            0.0
                      0.0            0.0           -3.391594E-02   0.0            0.0            0.0
        3      G      0.0            0.0            1.162375E-01   0.0            0.0            0.0
                      0.0            0.0            2.545503E-02   0.0            0.0            0.0
        4      G      0.0            0.0            2.549485E-01   0.0            0.0            0.0
                      0.0            0.0           -6.140902E-02   0.0            0.0            0.0
        5      G      0.0            0.0            3.571462E-01   0.0            0.0            0.0
                      0.0            0.0            2.425030E-02   0.0            0.0            0.0
        6      G      0.0            0.0            4.976830E-01   0.0            0.0            0.0
                      0.0            0.0           -5.850959E-02   0.0            0.0            0.0
        7      G      0.0            0.0            6.736954E-01   0.0            0.0            0.0
                      0.0            0.0            6.928696E-03   0.0            0.0            0.0
        8      G      0.0            0.0            8.139030E-01   0.0            0.0            0.0
                      0.0            0.0           -6.776229E-02   0.0            0.0            0.0
        9      G      0.0            0.0            9.668907E-01   0.0            0.0            0.0
                      0.0            0.0           -1.876364E-02   0.0            0.0            0.0
       10      G      0.0            0.0            1.097138E+00   0.0            0.0            0.0
                      0.0            0.0           -8.202810E-02   0.0            0.0            0.0
       11      G      0.0            0.0            0.0            0.0            0.0            0.0
                      0.0            0.0            0.0            0.0            0.0            0.0

 COMPLEX EIGENVALUE =  1.013381E-01,  1.921735E+01
                                      C O M P L E X   E I G E N V E C T O R   NO.         7
                                                         (REAL/IMAGINARY)

 POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
        1      G      0.0            0.0            3.087929E-02   0.0            0.0            0.0
                      0.0            0.0            1.569297E-02   0.0            0.0            0.0
        2      G      0.0            0.0            8.654780E-02   0.0            0.0            0.0
                      0.0            0.0           -3.018055E-02   0.0            0.0            0.0
        3      G      0.0            0.0            1.257552E-01   0.0            0.0            0.0
                      0.0            0.0            2.450372E-02   0.0            0.0            0.0
        4      G      0.0            0.0            2.244809E-01   0.0            0.0            0.0
                      0.0            0.0           -5.494687E-02   0.0            0.0            0.0
        5      G      0.0            0.0            3.649569E-01   0.0            0.0            0.0
                      0.0            0.0            2.340965E-02   0.0            0.0            0.0
        6      G      0.0            0.0            4.677418E-01   0.0            0.0            0.0
                      0.0            0.0           -5.238892E-02   0.0            0.0            0.0
        7      G      0.0            0.0            6.779492E-01   0.0            0.0            0.0
                      0.0            0.0            5.586534E-03   0.0            0.0            0.0
        8      G      0.0            0.0            7.839131E-01   0.0            0.0            0.0
                      0.0            0.0           -6.282084E-02   0.0            0.0            0.0
        9      G      0.0            0.0            9.677300E-01   0.0            0.0            0.0
                      0.0            0.0           -2.040747E-02   0.0            0.0            0.0
       10      G      0.0            0.0            1.068483E+00   0.0            0.0            0.0
                      0.0            0.0           -7.822070E-02   0.0            0.0            0.0
       11      G      0.0            0.0            0.0            0.0            0.0            0.0
                      0.0            0.0            0.0            0.0            0.0            0.0
```

Listing 8-7 Output for Jet Transport Wing by Lifting Surface Theory (Continued)

```
COMPLEX EIGENVALUE = -1.002459E+00,  0.000000E+00
                                 C O M P L E X   E I G E N V E C T O R   NO.        12
                                                   (REAL/IMAGINARY)

POINT ID.   TYPE         T1            T2            T3            R1            R2            R3
       1      G      0.0           0.0           4.771255E-02  0.0           0.0           0.0
                     0.0           0.0           0.0           0.0           0.0           0.0
       2      G      0.0           0.0           3.074158E-02  0.0           0.0           0.0
                     0.0           0.0           0.0           0.0           0.0           0.0
       3      G      0.0           0.0           1.514307E-01  0.0           0.0           0.0
                     0.0           0.0           0.0           0.0           0.0           0.0
       4      G      0.0           0.0           1.231133E-01  0.0           0.0           0.0
                     0.0           0.0           0.0           0.0           0.0           0.0
       5      G      0.0           0.0           3.785414E-01  0.0           0.0           0.0
                     0.0           0.0           0.0           0.0           0.0           0.0
       6      G      0.0           0.0           3.449427E-01  0.0           0.0           0.0
                     0.0           0.0           0.0           0.0           0.0           0.0
       7      G      0.0           0.0           7.000237E-01  0.0           0.0           0.0
                     0.0           0.0           0.0           0.0           0.0           0.0
       8      G      0.0           0.0           6.606572E-01  0.0           0.0           0.0
                     0.0           0.0           0.0           0.0           0.0           0.0
       9      G      0.0           0.0           1.028760E+00  0.0           0.0           0.0
                     0.0           0.0           0.0           0.0           0.0           0.0
      10      G      0.0           0.0           9.876114E-01  0.0           0.0           0.0
                     0.0           0.0           0.0           0.0           0.0           0.0
      11      G      0.0           0.0           0.0           0.0           0.0           0.0
                     0.0           0.0           0.0           0.0           0.0           0.0

COMPLEX EIGENVALUE =  1.024470E+00,  0.000000E+00
                                 C O M P L E X   E I G E N V E C T O R   NO.        18
                                                   (REAL/IMAGINARY)

POINT ID.   TYPE         T1            T2            T3            R1            R2            R3
       1      G      0.0           0.0           4.814341E-02  0.0           0.0           0.0
                     0.0           0.0           0.0           0.0           0.0           0.0
       2      G      0.0           0.0           3.111237E-02  0.0           0.0           0.0
                     0.0           0.0           0.0           0.0           0.0           0.0
       3      G      0.0           0.0           1.520088E-01  0.0           0.0           0.0
                     0.0           0.0           0.0           0.0           0.0           0.0
       4      G      0.0           0.0           1.237039E-01  0.0           0.0           0.0
                     0.0           0.0           0.0           0.0           0.0           0.0
       5      G      0.0           0.0           3.792227E-01  0.0           0.0           0.0
                     0.0           0.0           0.0           0.0           0.0           0.0
       6      G      0.0           0.0           3.457828E-01  0.0           0.0           0.0
                     0.0           0.0           0.0           0.0           0.0           0.0
       7      G      0.0           0.0           6.995916E-01  0.0           0.0           0.0
                     0.0           0.0           0.0           0.0           0.0           0.0
       8      G      0.0           0.0           6.606771E-01  0.0           0.0           0.0
                     0.0           0.0           0.0           0.0           0.0           0.0
       9      G      0.0           0.0           1.026566E+00  0.0           0.0           0.0
                     0.0           0.0           0.0           0.0           0.0           0.0
      10      G      0.0           0.0           9.861466E-01  0.0           0.0           0.0
                     0.0           0.0           0.0           0.0           0.0           0.0
      11      G      0.0           0.0           0.0           0.0           0.0           0.0
                     0.0           0.0           0.0           0.0           0.0           0.0
```

Flutter and Divergence Analysis of Jet Transport Wing by Strip Theory (Example HA145C)

This example is the same BAH wing considered in Example HA145B (p. 428) with only the aerodynamic theory and the flutter solution method changed. Aerodynamic Strip Theory is used and the solution is obtained by the K-Flutter method. The spanwise divisions shown in Figure 8-3 are also used in the Strip Theory, and the analysis again assumes sea-level density.

Strip Theory Aerodynamics

CAERO4 4000 is the Bulk Data entry for the Strip Theory aerodynamics. It invokes property entry PAERO4 that lists the aerodynamic and geometrical characteristics of each strip. The basic coordinate system is specified and nonuniform strip divisions are given on AEFACT 77 for the six strips; the continuation entry tabulates the planform geometry at the root and tip chords. PAERO4 4001 provides CLA = 0 for no Prandtl-

Glauert compressibility correction, LCLA = 0 for the theoretical two-dimensional lift curve slope on each strip to be $c_{l_\alpha} = 2\pi$, CIRC = 0 for the exact circulation function of Theodorsen, and LCIRC = 0 since no approximation is used for the circulation function. The remaining required data provide any control surface geometry, and, since there is no aileron, DOCi = CAOCi = GAPOCi = 0.0 for all six strips.

SPLINE2 100 is the linear spline along the 35%-chord elastic axis that connects all 11 structural grid points to the five strips (IDs 4001 through 4005) outboard of the fuselage side, that is, the inboard strip (ID 4000), which is assumed to represent the fuselage, does not move.

The aerodynamics for the flutter analysis are specified on MKAERO1 entries for a Mach number $m = 0.0$ and reduced frequencies k from 0.0001 (to obtain the divergence speed) up to 1.5; the 11 values of k require two separate MKAERO1 entries. FLUTTER 30 specifies the K-method of flutter analysis with a density ratio of 1.0 on FLFACT 1, a Mach number $m = 0.0$ on FLFACT 2, and a series of reduced frequencies decreasing from $k = 0.20$ to $k = 0.0001$; the two small values of k determine the divergence speed, and the remaining values determine the flutter speed.

The K-method also requires an EIGC entry to specify the complex eigenvalue method. EIGC 20 requests the Upper Hessenberg method to determine all 10 eigenvalues with the modal participation factors (eigenvectors of the modal solution) normalized on their maximum component. The ENDDATA entry completes the Bulk Data Section.

The Case Control Section includes the title, subtitle, and label. ECHO = BOTH prints both the annotated and sorted input files. SPC = 1 refers to the SPC1 1 entry, which constrains the fuselage additionally in plunge, roll, and pitch. SDAMP = 2000 refers to the damping entry TABDMP1. The vibration control METHOD = 10 refers to EIGR 10. The complex eigenvalue control CMETHOD = 20 refers to EIGC 20, and the flutter control FMETHOD = 30 refers to FLUTTER 30, which specifies the K-method. SDISP(PLOT) = ALL and DISP(PLOT) = ALL save the eigenvector and displacement data for plotting but do not print them. Note that SDISP = ALL and DISP = ALL will lead to an extensive amount of printed output. The remaining Case Control entries set up the V-g and V-f curves for plotting. The command BEGIN BULK ends the Case Control Section.

The Executive Control Section begins with the identification ID MSC, HA145C. Time 5 limits CPU time to 5.0 minutes. SOL 145 calls for the Aerodynamic Flutter DMAP solution sequence, and CEND concludes the Executive Control Section. The input data echo is shown in Listing 8-8 followed by the sorted Bulk Data entries in Listing 8-9. Selected output data are shown in Listing 8-10 and in Figure 8-6. The primary results of the analysis are discussed as follows.

The K-flutter analysis shows the same number of instabilities as the PK-flutter analysis of Example HA145B (p. 428), but at somewhat different speeds because of the significant differences between Lifting Surface Theory and Strip Theory. The critical flutter speed in the V-g curve of Figure 8-6 or in the Flutter Summary for Point 6 ($k = 0.090$) is $1152 \text{ ft/s} = 786 \text{ mph}$. This speed is 9.1% higher than that obtained by Lifting Surface Theory. A comparison of the Lifting Surface and Strip Theory damping results is shown in Figure 8-7 for the critical second (torsion) flutter mode. The differences in frequencies are small whereas the differences in damping are substantial.

The divergence speeds are found from the K-flutter analysis at very low reduced frequencies. From the Flutter Summary, Point 12 ($k = 0.0010$) shows the lowest divergence speed to be 1421.4 ft/s (with an artificial structural damping of $g = -0.0250$), and Point 13 ($k = 0.0001$) shows the lowest divergence speed to be 1419.8 ft/s (with $g = -0.00303$). Point 13, corresponding to a very low value of k , is the more accurate result and agrees almost exactly with the value of 1419.9 ft/s obtained by regarding divergence as a static instability (eigenvalue) problem in Bisplinghoff, Ashley, and Halfman (1955) [Reference 8]. The critical speeds of the higher divergence modes are also estimated from Point 13. The second speed is 2873 ft/s and the third speed is 4486 ft/s, approximately in the ratio 1:2:3 as theoretically predicted for a uniform wing by Strip Theory. The divergence speed of 1420 ft/s from Strip Theory is 14.0% lower than the 1651 ft/s obtained from Lifting Surface Theory in Example HA145B.

It is important to note that in this example Strip Theory is conservative for the prediction of divergence, but unconservative for the prediction of flutter.

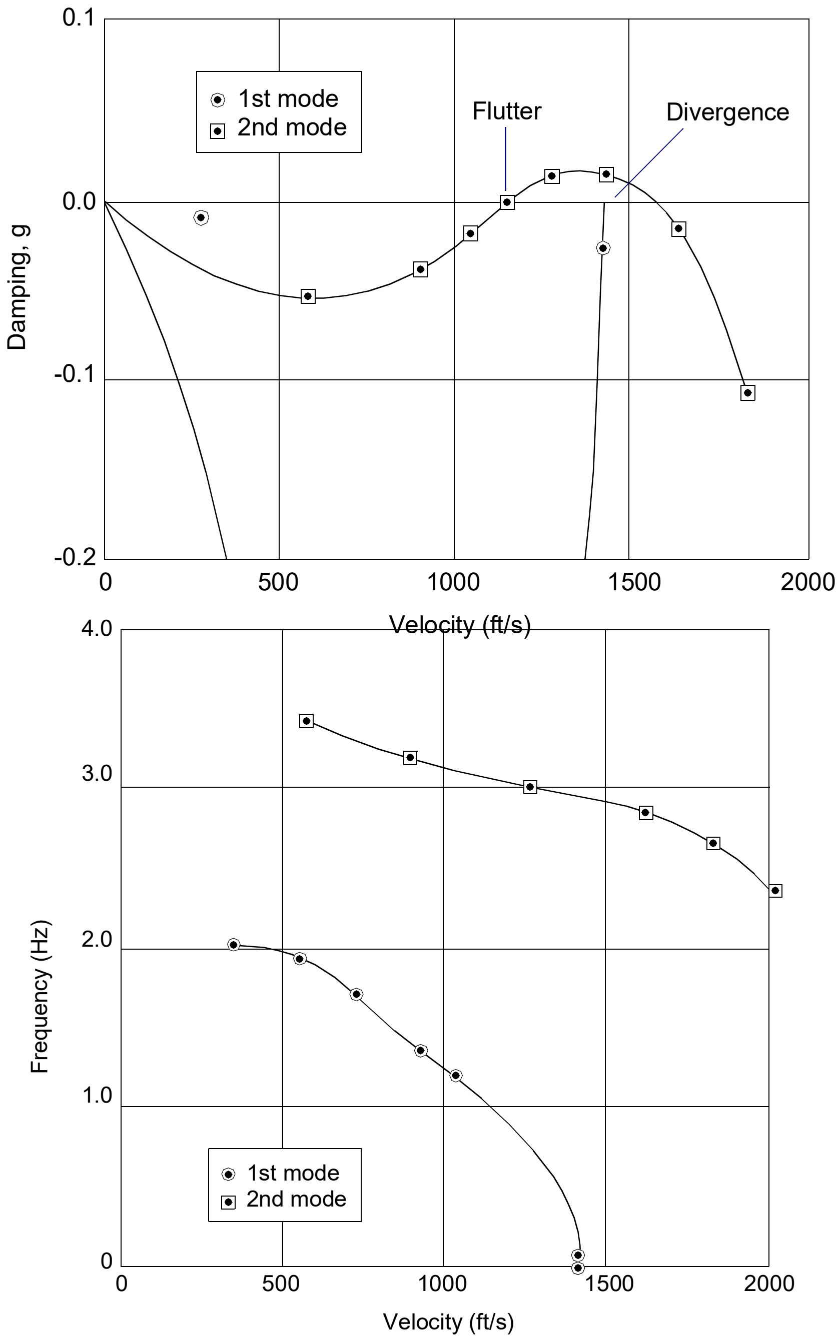

Figure 8-6 BAH Wing V-g and V-f Curves for First and Second Modes

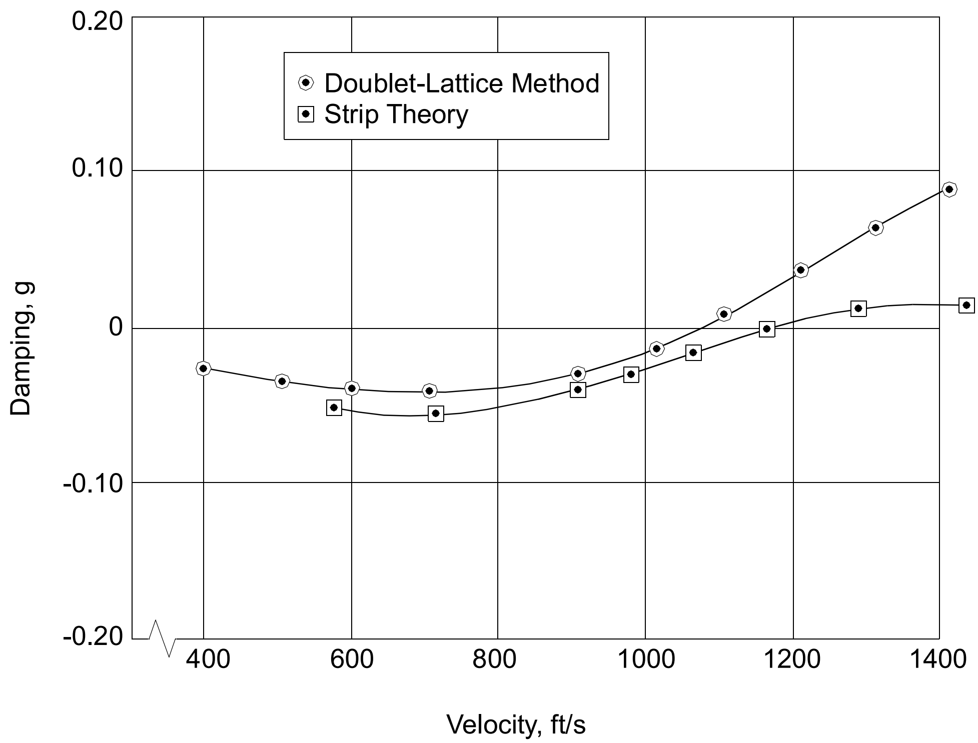

Figure 8-7 Stability Curves for Critical Torsion Mode of BAH Wing

Listing 8-8 Input for Jet Transport Wing by Strip Theory

```
    N A S T R A N   E X E C U T I V E   C O N T R O L   D E C K   E C H O

ID MSC, HA145C
$$$$$$$$    HANDBOOK FOR AEROELASTIC ANALYSIS EXAMPLE HA145C    $$$$$$$$
$                                                                      $
$       MODEL DESCRIPTION       BAH JET TRANSPORT WING EXAMPLE         $
$                               CANTILEVERED WING WITH TEN BEAM        $
$                               ELEMENTS AND DUMBBELL MASSES           $
$                                                                      $
$       SOLUTION                K METHOD OF FLUTTER ANALYSIS           $
$                               USING STRIP THEORY WITH THE EXACT      $
$                               THEODORSEN FUNCTION AT MACH NO. 0.0    $
$                                                                      $
$       OUTPUT                  TABULATED MODAL DEFLECTIONS PLUS       $
$                               X-Y PLOTS OF V-G FLUTTER DATA          $
$                                                                      $
$$$$$$$$                                                        $$$$$$$$
TIME 5 $ TIME IN CPU MINUTES
SOL  145 $ FLUTTER ANALYSIS
CEND
```

Listing 8-8 Input for Jet Transport Wing by Strip Theory

```
EXAMPLE HA145C: BAH JET TRANSPORT WING FLUTTER ANALYSIS                                                    PAGE     2
 CANTILEVERED, EXACT STRIP THEORY AT MACH NO. 0.0
 K-FLUTTER METHOD
                                    C A S E    C O N T R O L   D E C K   E C H O
            CARD
            COUNT
         TITLE = EXAMPLE HA145C: BAH JET TRANSPORT WING FLUTTER ANALYSIS
         SUBTI = CANTILEVERED, EXACT STRIP THEORY AT MACH NO. 0.0
         LABEL = K-FLUTTER METHOD
           ECHO         = BOTH
           SPC          = 1      $ FUSELAGE CONSTRAINT
           SDAMP        = 2000   $ STRUCTURAL DAMPING
           METHOD       = 10     $ MODIFIED GIVENS FOR VIBRATION ANALYSIS
           SVEC         = ALL    $ PRINT VIBRATION MODES
           CMETHOD      = 20     $ HESSENBERG METHOD FOR FLUTTER ANALYSIS
           FMETHOD      = 30     $ K-FLUTTER METHOD
         $---BE CAREFUL WITH EIGENVECTOR TABULATIONS:  THE SDISP=ALL COMMAND PRINTS
         $   ONE MODAL EIGENVECTOR PER PAGE FOR EACH EIGENVALUE AND FOR ALL THE
         $   VALUES OF REDUCED FREQUENCY; DISP=ALL PRINTS THE CORRESPONDING
         $   GRID DISPLACEMENTS ONE SET PER PAGE.  SDISP(PLOT)=ALL AND DISP(PLOT)
         $   =ALL SAVES THEM BUT DOES NOT PRINT THEM.
           SDISP(PLOT) = ALL    $ PLOT AND SAVE ALL MODAL PARTICIPATION FACTORS
           SET 10  = 1 THRU 5000
           DISP(PLOT)  = 10     $ PLOT AND SAVE STRUCTURAL DISPLACEMENTS IN SET 10
         OUTPUT(XYOUT)
           CSCALE 2.0
           PLOTTER NASTRAN
           CURVELINESYMBOL = -6
           YTTITLE = DAMPING  G
           YBTITLE =FREQUENCY  F HZ
           XTITLE  = VELOCITY  V (FT/SEC)
           XMIN  =    0.
           XMAX  = 2500.
           YTMIN =  -.6
           YTMAX =  +.1
           YBMIN =   0.
           YBMAX =  15.
           XTGRID LINES = YES
           XBGRID LINES = YES
           YTGRID LINES = YES
           YBGRID LINES = YES
           UPPER TICS  = -1
           TRIGHT TICS = -1
           BRIGHT TICS = -1
           XYPLOT VG / 1(G,F)  2(G,F)  3(G,F)  4(G,F)  5(G,F)  6(G,F)  7(G,F),
                        8(G,F)  9(G,F) 10(G,F) 11(G,F) 12(G,F) 13(G,F) 14(G,F),
                       15(G,F) 16(G,F) 17(G,F) 18(G,F) 19(G,F)
           CURVELINESYMBOL = -6
           YTTITLE = DAMPING  G
           YBTITLE =FREQUENCY  F HZ
           XTITLE  = VELOCITY  V (FT/SEC)
           XMIN  =    0.
           XMAX  = 1600.
           YTMIN =  -1.7
           YTMAX =   +.1
           YBMIN =   0.
           YBMAX =   2.5
           XTGRID LINES = YES
           XBGRID LINES = YES
           YTGRID LINES = YES
           YBGRID LINES = YES
           UPPER TICS  = -1
           TRIGHT TICS = -1
           BRIGHT TICS = -1
           XYPLOT VG / 1(G,F)  2(G,F)  3(G,F)  4(G,F)  5(G,F)  6(G,F)  7(G,F),
                        8(G,F)  9(G,F) 10(G,F) 11(G,F) 12(G,F) 13(G,F) 14(G,F),
                       15(G,F) 16(G,F) 17(G,F) 18(G,F) 19(G,F)
         BEGIN BULK
```

Listing 8-8 Input for Jet Transport Wing by Strip Theory

```
EXAMPLE HA145C: BAH JET TRANSPORT WING FLUTTER ANALYSIS                                                          PAGE     4
 CANTILEVERED, EXACT STRIP THEORY AT MACH NO. 0.0
 K-FLUTTER METHOD
                                          I N P U T   B U L K   D A T A   D E C K   E C H O

                          .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                           $*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
                           $                                                                        $
                           $        THE ANNOTATIONS IN THIS INPUT DECK ARE INTENDED TO              $
                           $        EXPLAIN THE DATA ON THE CARD IMAGES FOR THIS SPECIFIC           $
                           $        EXAMPLE WITHOUT REFERENCE TO THE VARIOUS MANUALS WHERE          $
                           $        MORE GENERAL DESCRIPTIONS WILL BE FOUND.                        $
                           $                                                                        $
                           $*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
                           $
                           INCLUDE BAH_STRUCT.DAT
                           $                                                                        $
                           INCLUDE BAH_MASS.DAT
                           $                                                                        $
                           $                    * * STRUCTURAL CONSTRAINTS * *                      $
                           $                                                                        $
                           $        THE SPC ENTRY DEFINES SETS OF SINGLE-POINT CONSTRAINTS          $
                           $        AND ENFORCED DISPLACEMENTS.  IT LISTS THE ID, GRID POINT        $
                           $        NO., CONSTRAINED DOFS AND VALUE OF AN ENFORCED DISPLACE-        $
                           $        MENT.                                                           $
                           $                                                                        $
                           $       SID     G       C       D
                           SPC     1       11      345
                           $                                                                        $
                           $                   * * STRUCTURAL DAMPING * *                           $
                           $                                                                        $
                           $        THE PARAMETER KDAMP DETERMINES THE MANNER OF INCLUSION          $
                           $        OF STRUCTURAL DAMPING IN EQUATIONS OF MOTION (SEE HANDBOOK      $
                           $        FOR DYNAMIC ANALYSIS, SECT. 3.2.2).  IF SET TO -1, MODAL        $
                           $        DAMPING IS PUT INTO COMPLEX STIFFNESS MATRIX AS STRUCTURAL      $
                           $        DAMPING.                                                        $
                           $                                                                        $
                           $       N       V1      V2
                           PARAM   KDAMP   -1
                           $                                                                        $
                           $        THE TABDMP1 ENTRY DEFINES MODAL DAMPING AS A TABULAR            $
                           $        FUNCTION OF FREQUENCY.  THE DAMPING LEVELS ARE LINEAR           $
                           $        BETWEEN THE FREQUENCY AND DAMPING PAIRS AND ARE EXTRAP-         $
                           $        OLATED OUTSIDE THE TABULATED FREQUENCY RANGE.                   $
                           $                                                                        $
                           $       ID      TYPE                                                     +TDP
                           TABDMP1 2000    G                                                        +T2000
                           $       F1      G1      F2      G2      ETC             ENDT
                           +T2000  0.0     0.0     10.0    0.0     ENDT
                           $
                           $
                           $                     * * * AERODYNAMIC DATA * * *                       $
                           $                                                                        $
                           $                          (LB-IN-SEC SYSTEM)                            $
                           $                                                                        $
                           $                       * * ELEMENT GEOMETRY * *                         $
                           $                                                                        $
                           $        THE AERO ENTRY SPECIFIES THE AERO COORDINATE SYSTEM, THE        $
                           $        VELOCITY (USED FOR DATA RECOVERY), THE REFERENCE CHORD          $
                           $        AND FLUID DENSITY, PLUS SYMMETRY KEYS.  SYMXZ=1 INDICATES       $
                           $        THAT THE MODEL IS MOUNTED WITH A ROOT REFLECTION PLANE;         $
                           $        SYMXY = 0 INDICATES THAT THE MODEL IS MOUNTED FAR ENOUGH        $
                           $        FROM THE FLOOR SO THAT REFLECTION EFFECTS ARE NEGLIGIBLE.       $
                           $        NOTE THAT THE THE DIMENSIONS OF THE REFERENCE DENSITY OF        $
                           $        AIR ARE SNAILS PER CUBIC INCH, NOT POUNDS PER CUBIC INCH.       $
                           $                                                                        $
                           $       ACSID   VELOCITY REFC   RHOREF  SYMXZ   SYMXY
                           AERO    1               131.232 1.1468-7  1
                           $                                                                        $
                           $        THIS CORD2R ENTRY DEFINES THE AERO COORDINATE SYSTEM            $
                           $        FLAGGED BY THE AERO ENTRY.  LISTED ARE THE ORIGIN, A            $
                           $        POINT ALONG THE Z AXIS AND A POINT IN THE X-Z PLANE,            $
                           $        ALL IN THE RID COORDINATE SYSTEM.  NOTE THAT IN THIS            $
                           $        COORDINATE SYSTEM THE UPSIDE DOWN AND BACKWARDS STRUC-          $
                           $        TURE WILL FLY UPSIDE UP AND FORWARD.                            $
                           $                                                                        $
                           $       CID     RID     A1      A2      A3      B1      B2      B3
                           CORD2R  1               0.      0.      0.      0.      0.      -1.      +C1
                           $       C1      C2      C3
                           +C1     -1.     0.      0.
                           $                                                                        $
                           $                                                                        $
```

Listing 8-8 Input for Jet Transport Wing by Strip Theory

```
$       THE CAERO4 ENTRY IS USED TO SPECIFY STRIP THEORY AERO.        $
$       PID IDENTIFIES A PAERO4 ENTRY WHERE THE ELEMENT PROPERTIES    $
$       ARE GIVEN, CP DEFAULTS TO THE BASIC COORDINATE SYSTEM,        $
$       NSPAN WOULD BE THE NUMBER OF EQUAL SPAN STRIPS, HOWEVER       $
$       LSPAN SPECIFIES THE AEFACT ENTRY WHERE THE UNEQUAL STRIP      $
$       WIDTHS ARE DEFINED.  THE CONTINUATION ENTRY DEFINES THE       $
$       INBD AND OUTBD LEADING EDGE POINTS AND THE CHORDS.            $
$                                                                     $
$       EID     PID     CP      NSPAN   LSPAN
CAERO4  4000    4001    0       0       77                            +BAH
$       X1      Y1      Z1      X12     X4      Y4      Z4      X43
+BAH    78.75   0.0     0.0     225.0   35.0    500.0   0.0     100.0
$                                                                     $
$       THIS AEFACT ENTRY GIVES THE EDGES OF THE STRIPS IN PERCENT    $
$       OF SPAN.                                                      $
$                                                                     $
$       SID     D1      D2      D3      ETC
AEFACT  77      .0      .09     .276    .454    .636    .826    1.0
$                                                                     $
$       THE PAERO4 ENTRY DEFINES PROPERTIES OF THE STRIP ELEMENTS     $
$       FOR STRIP THEORY AERODYNAMICS.  IT OFFERS A WIDE VARIETY      $
$       OF OPTIONS.  CLA DEFAULTS TO NO COMPRESSIBILITY CORRECTION    $
$       AND NO CORRECTIONS OF LIFT CURVE SLOPES.  LCLA MUST BE ZERO   $
$       WHEN CLA IS ZERO.  CIRC=0 SPECIFIES THE EXACT EXPRESSION FOR  $
$       THE THEODORSEN CIRCULATION FUNCTION.  DOC, CAOC AND GAPOC     $
$       ARE REQUIRED EVEN THOUGH THE STRIP HAS NO CONTROL SURFACE.    $
$       IN FRACTIONS OF CHORD THESE ARE THE DISTANCE FROM THE QUARTER $
$       CHORD TO THE HINGE LINE, THE CONTROL SURFACE CHORD AND THE    $
$       GAP BETWEEN THE PRIMARY SURFACE AND THE CONTROL SURFACE.      $
$       CAOC1=0. SPECIFIES NO CONTROL SURFACE.                        $
$                                                                     $
$       PID     CLA     LCLA    CIRC    LCIRC   DOC1    CAOC1   GAPOC1
PAERO4  4001    0       0       0       0       0.0     0.0     0.0     +PA41
+PA41   0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     +PA42
+PA42   0.0     0.0     0.0     0.0     0.0     0.0     0.0
$                                                                     $
$               * * SPLINE FIT ON THE LIFTING SURFACES * *            $
$                                                                     $
$                     * BEAM SPLINE FIT ON THE WING *                 $
$                                                                     $
$       THE SPLINE2 ENTRY SPECIFIES A BEAM SPLINE FOR INTERPOLAT-     $
$       ION OVER THE REGION OF THE CAERO ENTRY (ID1 AND ID2 ARE       $
$       THE FIRST AND LAST BOXES IN THIS REGION).  SETG REFERS        $
$       TO A SET1 ENTRY WHERE THE STRUCTURAL GRID POINTS ARE          $
$       DEFINED.  DZ AND DTOR ARE SMOOTHING CONSTANTS FOR LINEAR      $
$       ATTACHMENT AND TORSIONAL FLEXIBILITIES.  DTHX AND DTHY        $
$       ARE ROTATIONAL ATTACHMENT FLEXIBILITIES. CID IDENTIFIES       $
$       THE SPLINE AXIS.                                              $
$                                                                     $
$       EID     CAERO   ID1     ID2     SETG    DZ      DTOR    CID
SPLINE2 100     4000    4001    4005    14      .0      1.0     0       +SP100
$       DTHX    DTHY
+SP100  -1.0    -1.0
$                                                                     $
$       THE SET1 ENTRY DEFINES THE SETS OF STRUCTURAL GRID POINTS     $
$       TO BE USED BY THE BEAM SPLINE FOR INTERPOLATION.              $
$                                                                     $
$       SID     G1      G2      G3      G4      G5      G6
SET1    14      1       THRU    11
$                                                                     $
$                  * * * SOLUTION SPECIFICATIONS * * *                $
$                                                                     $
$                    * * AERODYNAMIC CONDITIONS * *                   $
$                                                                     $
$       ALL COMBINATIONS OF MACH NUMBER AND REDUCED FREQUENCY LISTED  $
$       ON THE MKAERO1 ENTRY AND ITS CONTINUATION ENTRY WILL BE USED  $
$       TO GENERATE GENERALIZED AERO FORCE MATRICES.  IF MORE THAN    $
$       EIGHT MACH NO.S OR REDUCED FREQUENCIES ARE REQUIRED A SECOND  $
$       MKAERO1 ENTRY IS NECESSARY.                                   $
$                                                                     $
$        M1     M2      M3      ETC
MKAERO1 0.0                                                           +MK1
$       K1      K2      K3      K4      ETC
+MK1    0.0001  0.02    0.04    0.06    0.08    0.10    0.12    0.20
MKAERO1 0.0                                                           +MK2
+MK2    0.50    1.0     1.5
$                                                                     $
$                      * * SOLUTION PARAMETERS * *                    $
$                                                                     $
$       THE FLUTTER ENTRY DEFINES THE METHOD OF SOLUTION, IDENTIFIES  $
$       THE FLFACT ENTRIES THAT FOLL0W, SPECIFIES THE INTERPOLATION   $
$       METHOD, THE NUMBER OF ROOTS DESIRED IN THE OUTPUT AND THE     $
$       CRITERION FOR CONVERGENCE (DEFAULT IS 10-3).                  $
```

Listing 8-8 Input for Jet Transport Wing by Strip Theory

```
$                                                                       $
$       SID     METHOD  DENS    MACH    VEL     IMETH   NVALUE  EPS     $
FLUTTER 30      K       1       2       3       L       6
$                                                                       $
$        FLFACT ENTRIES ARE USED TO SPECIFY DENSITY RATIOS, MACH NO.S   $
$        AND REDUCED FREQUENCIES/VELOCITIES FOR FLUTTER ANALYSES.       $
$                                                                       $
$       SID     F1      F2      F3      F4      F5      F6      F7      $
FLFACT  1       1.                                                      DENSITY
FLFACT  2       .0                                                      MACH NO
FLFACT  3       0.20    0.16    0.12    0.11    0.10    0.09    0.08    +FLF3
+FLF3   0.07    0.06    0.05    0.04    0.001   0.0001
$                                                                       $
$        THE PARAM,LMODES,N ENTRY SPECIFIES THAT N MODES ARE TO BE      $
$        USED IN THE FLUTTER ANALYSIS.                                  $
$                                                                       $
$       N       V1      V2                                              $
PARAM   LMODES  10
$                                                                       $
$        THE PARAM,VREF,C ENTRY SPECIFIES A CONVERSION FACTOR TO BE     $
$        USED TO CONVERT THE DIMENSIONS OF THE OUTPUT VELOCITIES BY     $
$        DIVIDING BY C, IN THIS CASE BY 12.0 IN/FT TO PRINT VEL-        $
$        OCITIES IN FT/SEC RATHER THAN IN/SEC.                          $
$                                                                       $
$       N       V1      V2                                              $
PARAM   VREF    12.0
$                                                                       $
$                    * * EIGENSOLUTION PARAMETERS * *                   $
$                                                                       $
$        THE EIGR ENTRY SPECIFIES THE METHOD OF EXTRACTING THE EIGEN-   $
$        SOLUTIONS OF THE STRUCTURE IN A VACUUM; IN THIS CASE THE       $
$        MODIFIED GIVENS METHOD.  THREE MODES ARE DESIRED, NORMAL-      $
$        IZED ON THE MAXIMUM DISPLACEMENTS.                             $
$                                                                       $
$       SID     METHOD  F1      F2              ND                      $
EIGR    10      MGIV                            10                      +EIGR
$       NORM    G       C                                               $
+EIGR   MAX
$                                                                       $
$        THE EIGC ENTRY DEFINES DATA NEEDED TO PERFORM A COMPLEX        $
$        EIGENVALUE ANALYSIS.  THIS ONE SPECIFIES THAT THE UPPER        $
$        HESSENBERG METHOD BE USED TO EXTRACT COMPLEX EIGENVALUES       $
$        AND THAT THE EIGENVECTORS BE NORMALIZED ON THEIR MAXIMUM       $
$        COMPONENTS.  IF THEY WERE TO HAVE BEEN NORMALIZED ON A         $
$        POINT THE GRID AND DOF COMPONENT WOULD HAVE BEEN REQUIRED.     $
$        THE CONVERGENCE CRITERION DEFAULTS TO 1.0-4 FOR THE INVERSE    $
$        POWER METHOD, TO 1.0-11 FOR THE DETERMINANT METHOD AND TO      $
$        1.0-15 FOR THE HESSENBERG METHOD.  WHEN THE HESSENBERG         $
$        METHOD IS SPECIFIED ALL ENTRIES ON THE CONTINUATION ENTRY      $
$        EXCEPT THE NUMBER OF DESIRED ROOTS (NDL) ARE IGNORED.          $
$
$       SID     METHOD  NORM    G       C       E
EIGC    20      HESS    MAX                                             +EC
$       ALPHAA1 OMEGAA1 ALPHAB1 OMEGAB1 L1      NEL     NDL
+EC                                                     10
ENDDATA
INPUT BULK DATA CARD COUNT =     359
```

Listing 8-9 Sorted Bulk Data Entries for Jet Transport Wing by Strip Theory

```
EXAMPLE HA145C: BAH JET TRANSPORT WING FLUTTER ANALYSIS                                                              PAGE 12
      CANTILEVERED, EXACT STRIP THEORY AT MACH NO. 0.0
     K-FLUTTER METHOD
                                                        S O R T E D   B U L K   D A T A   E C H O
             CARD
             COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                1-        AEFACT  77      .0      .09     .276    .454    .636    .826    1.0
                2-        AERO    1               131.232 1.1468-71
                3-        CAERO4  4000    4001    0       0       77                              +BAH
                4-        +BAH    78.75   0.0     0.0     225.0   35.0    500.0   0.0     100.0
                5-        CMASS2  121     5248.7  1       3
                6-        CMASS2  122     134.9   1       3       2       3
                7-        CMASS2  123     790.3   2       3
                8-        CMASS2  341     9727.   3       3
                9-        CMASS2  342     11005.  3       3       4       3
               10-        CMASS2  343     473.    4       3
               11-        CMASS2  561     3253.6  5       3
               12-        CMASS2  562     -139.7  5       3       6       3
               13-        CMASS2  563     946.3   6       3
               14-        CMASS2  781     2617.8  7       3
               15-        CMASS2  782     21.     7       3       8       3
               16-        CMASS2  783     782.3   8       3
               17-        CMASS2  9101    494.8   9       3
               18-        CMASS2  9102    -7.3    9       3       10      3
               19-        CMASS2  9103    185.2   10      3
               20-        CONM1   1       11                                                      +51
               21-        +51     17400.                          4.37+7                          +52
               22-        +52             4.35+09
               23-        CORD2R  1               0.      0.      0.      0.      0.      -1.     +C1
               24-        +C1     -1.     0.      0.
               25-        EIGC    20      HESS    MAX                                             +EC
               26-        +EC                                                     10
               27-        EIGR    10      MGIV                            10                      +EIGR
               28-        +EIGR   MAX
               29-        FLFACT  1       1.                                                      DENSITY
               30-        FLFACT  2       .0                                                      MACH NO
               31-        FLFACT  3       0.20    0.16    0.12    0.11    0.10    0.09    0.08    +FLF3
               32-        +FLF3   0.07    0.06    0.05    0.04    0.001   0.0001
               33-        FLUTTER 30      K       1       2       3       L       6
               34-        GENEL   432             1       3       2       3       3       3       +01
               35-        +01     4       3       5       3       6       3       7       3       +02
               36-        +02     8       3       9       3       10      3                       +03
               37-        +03     UD              11      3       11      4       11      5       +04
               38-        +04     11      6                                                       +05
               39-        +05     Z       8.7172-61.3361-61.2778-56.2720-61.6251-51.0492-52.0478-5+06
               40-        +06     1.5630-52.4285-52.0403-53.0861-56.2720-63.2297-51.0492-53.3529-5+07
               41-        +07     1.5630-53.5021-52.0257-53.5785-52.7732-51.5726-54.8255-53.7628-5+08
               42-        +08     7.3284-56.4338-59.5810-58.8378-56.3749-53.7628-58.0136-56.4338-5+09
               43-        +09     1.0012-48.8378-51.1811-41.2758-41.1344-41.9350-41.8160-42.5283-4+10
               44-        +10     2.4294-41.6999-41.8160-42.2920-42.4294-42.8249-43.6862-43.5052-4+11
               45-        +11     5.2675-45.1171-44.2292-45.1171-45.7187-48.4840-48.2340-49.2340-4+12
               46-        +12     S       1.0     90.0    -20.25  45.0    1.0     90.0    81.0    +13
               47-        +13     45.0    1.0     186.0   -17.85  141.0   1.0     186.0   71.4    +14
               48-        +14     141.0   1.0     268.0   -15.80  223.0   1.0     268.0   63.2    +15
               49-        +15     223.0   1.0     368.0   -13.30  323.0   1.0     368.0   53.2    +16
               50-        +16     323.0   1.0     458.0   -11.05  413.0   1.0     458.0   44.2    +17
               51-        +17     413.0
               52-        GRID    1               20.25   90.                     12456
               53-        GRID    2               -81.    90.                     12456
               54-        GRID    3               17.85   186.                    12456
               55-        GRID    4               -71.4   186.                    12456
               56-        GRID    5               15.8    268.                    12456
               57-        GRID    6               -63.2   268.                    12456
               58-        GRID    7               13.3    368.                    12456
               59-        GRID    8               -53.2   368.                    12456
               60-        GRID    9               11.05   458.                    12456
               61-        GRID    10              -44.2   458.                    12456
               62-        GRID    11              0.0     0.                      126
               63-        MKAERO1 0.0                                                             +MK1
               64-        +MK1    0.0001  0.02    0.04    0.06    0.08    0.10    0.12    0.20
               65-        MKAERO1 0.0                                                             +MK2
               66-        +MK2    0.50    1.0     1.5
               67-        PAERO4  4001    0       0       0       0       0.0     0.0     0.0     +PA41
               68-        +PA41   0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     +PA42
               69-        +PA42   0.0     0.0     0.0     0.0     0.0     0.0     0.0
               70-        PARAM   GRDPNT  11
               71-        PARAM   KDAMP   -1
               72-        PARAM   LMODES  10
               73-        PARAM   VREF    12.0
               74-        PARAM   WTMASS  .0025907
               75-        SET1    14      1       THRU    11
               76-        SPC     1       11      345
               77-        SPLINE2 100     4000    4001    4005    14      .0      1.0     0       +SP100
               78-        +SP100  -1.0    -1.0
               79-        TABDMP1 2000                                                            +T2000
               80-        +T2000  0.0     0.0     10.0    0.0     ENDT
                          ENDDATA
                    TOTAL COUNT=        81
```

Listing 8-10 Output Data for Jet Transport Wing by Strip Theory

```
EXAMPLE HA145C: BAH JET TRANSPORT WING FLUTTER ANALYSIS                                                      PAGE 15
     CANTILEVERED, EXACT STRIP THEORY AT MACH NO. 0.0
    K-FLUTTER METHOD
                              O U T P U T   F R O M   G R I D   P O I N T   W E I G H T   G E N E R A T O R
                                                  REFERENCE POINT =       11
                                                           M O
                  *  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00 *
                  *  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00 *
                  *  0.000000E+00  0.000000E+00  4.191900E+04  5.128960E+06 -1.642074E+05  0.000000E+00 *
                  *  0.000000E+00  0.000000E+00  5.128960E+06  1.350243E+09 -2.381847E+07  0.000000E+00 *
                  *  0.000000E+00  0.000000E+00 -1.642074E+05 -2.381847E+07  4.458782E+09  0.000000E+00 *
                  *  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00 *
                                                          S
                                       *  1.000000E+00  0.000000E+00  0.000000E+00 *
                                       *  0.000000E+00  1.000000E+00  0.000000E+00 *
                                       *  0.000000E+00  0.000000E+00  1.000000E+00 *
                              DIRECTION
                         MASS AXIS SYSTEM (S)     MASS              X-C.G.        Y-C.G.        Z-C.G.
                                 X            0.000000E+00      0.000000E+00  0.000000E+00  0.000000E+00
                                 Y            0.000000E+00      0.000000E+00  0.000000E+00  0.000000E+00
                                 Z            4.191900E+04      3.917256E+00  1.223541E+02  0.000000E+00
                                                         I(S)
                                       *  7.226942E+08  3.727022E+06  0.000000E+00 *
                                       *  3.727022E+06  4.458139E+09  0.000000E+00 *
                                       *  0.000000E+00  0.000000E+00  0.000000E+00 *
                                                        I(Q)
                                       *  4.458143E+09                             *
                                       *                7.226906E+08               *
                                       *                              0.000000E+00 *
                                                          Q
                                       *  9.977437E-04  9.999995E-01  0.000000E+00 *
                                       * -9.999995E-01  9.977437E-04  0.000000E+00 *
                                       *  0.000000E+00  0.000000E+00  1.000000E+00 *

                                                    R E A L   E I G E N V A L U E S
MODE    EXTRACTION    EIGENVALUE          RADIANS           CYCLES           GENERALIZED       GENERALIZED
 NO.       ORDER                                                                 MASS           STIFFNESS
     1       1       1.637768E+02     1.279753E+01     2.036790E+00     8.160930E+00     1.336571E+03
     2       2       4.982469E+02     2.232145E+01     3.552568E+00     5.525822E+01     2.753224E+04
     3       3       2.092550E+03     4.574440E+01     7.280447E+00     7.079897E+00     1.481504E+04
     4       4       5.402874E+03     7.350424E+01     1.169856E+01     8.652712E+00     4.674951E+04
     5       5       8.742090E+03     9.349915E+01     1.488085E+01     4.002357E+00     3.498896E+04
     6       8       1.766007E+04     1.328912E+02     2.115029E+01     3.883447E+00     6.858195E+04
     7       6       2.398459E+04     1.548696E+02     2.464826E+01     3.597392E+00     8.628196E+04
     8      10       4.211864E+04     2.052283E+02     3.266309E+01     3.142601E+00     1.323621E+05
     9       9       6.020812E+04     2.453734E+02     3.905239E+01     1.016253E+00     6.118669E+04
    10       7       9.183204E+04     3.030380E+02     4.823000E+01     8.617019E+00     7.913184E+05

   EIGENVALUE =  1.637768E+02
       CYCLES =  2.036790E+00          R E A L   E I G E N V E C T O R   N O .          1

   POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
         1      G                                      4.518474E-02
         2      G                                      4.250221E-02
         3      G                                      1.482559E-01
         4      G                                      1.437271E-01
         5      G                                      3.794104E-01
         6      G                                      3.767312E-01
         7      G                                      6.929946E-01
         8      G                                      6.926546E-01
         9      G                                      9.989689E-01
        10      G                                      1.000000E+00

   EIGENVALUE =  4.982469E+02
       CYCLES =  3.552568E+00          R E A L   E I G E N V E C T O R   N O .          2

   POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
         1      G                                     -1.635563E-01
         2      G                                      5.449901E-01
         3      G                                     -2.796319E-01
         4      G                                      1.000000E+00
         5      G                                     -2.267440E-01
         6      G                                      9.465655E-01
         7      G                                     -1.388892E-01
         8      G                                      8.878612E-01
         9      G                                     -3.973597E-02
        10      G                                      8.224477E-01
```

Listing 8-10 Output Data for Jet Transport Wing by Strip Theory (Continued)

```
                                                FLUTTER  SUMMARY

POINT =  1    MACH NUMBER =  0.0000     DENSITY RATIO =  1.0000E+00     METHOD = K

KFREQ        1./KFREQ        VELOCITY        DAMPING         FREQUENCY         COMPLEX     EIGENVALUE
0.2000     5.0000000E+00   3.5462509E+02  -2.0858943E-01   2.0643868E+00  -4.3215588E+02   4.1881943E+03
0.2000     5.0000000E+00   5.8322821E+02  -5.2674945E-02   3.3951595E+00  -1.8401012E+02   6.9914707E+03
0.2000     5.0000000E+00   1.2520754E+03  -2.3927695E-01   7.2887340E+00  -1.7359998E+03   1.4715182E+04
0.2000     5.0000000E+00   1.7207372E+03  -9.8075986E-02   1.0016965E+01  -1.0065363E+03   2.0574883E+04
0.2000     5.0000000E+00   1.9962714E+03  -1.5567349E-01   1.1620938E+01  -1.8368853E+03   2.3741326E+04
0.2000     5.0000000E+00   3.2160227E+03  -3.7120324E-01   1.8721504E+01  -6.6058672E+03   3.6778152E+04

POINT =  2    MACH NUMBER =  0.0000     DENSITY RATIO =  1.0000E+00     METHOD = K

KFREQ        1./KFREQ        VELOCITY       DAMPING          FREQUENCY         COMPLEX       EIGENVALUE
0.1600     6.2500000E+00   4.4598291E+02  -2.8613585E-01   2.0769680E+00  -7.2885205E+02   5.1966719E+03
0.1600     6.2500000E+00   7.1119800E+02  -5.5524200E-02   3.3120899E+00  -2.3647678E+02   8.5245313E+03
0.1600     6.2500000E+00   1.5065197E+03  -3.0820668E-01   7.0159483E+00  -2.6319680E+03   1.7475635E+04
0.1600     6.2500000E+00   1.9703566E+03   1.7822902E-03   9.1760645E+00   2.1070440E+01   2.3644250E+04
0.1600     6.2500000E+00   2.4891079E+03  -2.6804453E-01   1.1591919E+01  -3.8329753E+03   2.9104336E+04
0.1600     6.2500000E+00   3.6857942E+03  -2.0898052E-01   1.7164955E+01  -4.4995903E+03   4.3527434E+04

POINT =  3   MACH NUMBER =  0.0000     DENSITY RATIO =  1.0000E+00     METHOD = K

KFREQ       1./KFREQ        VELOCITY       DAMPING           FREQUENCY          COMPLEX      EIGENVALUE
0.1200     8.3333340E+00   5.9679846E+02  -4.3520951E-01   2.0844936E+00  -1.3976279E+03   6.7137329E+03
0.1200     8.3333340E+00   9.0675781E+02  -3.9083730E-02   3.1671174E+00  -2.1243411E+02   1.0874868E+04
0.1200     8.3333340E+00   1.8064015E+03  -2.5740314E-01   6.3093863E+00  -2.6800193E+03   2.1162908E+04
0.1200     8.3333340E+00   2.4507854E+03  -1.1014013E-04   8.5600863E+00  -1.6195790E+00   2.9409426E+04
0.1200     8.3333340E+00   3.0537751E+03  -3.9544508E-01   1.0666204E+01  -6.6144561E+03   3.4713566E+04
0.1200     8.3333340E+00   4.3100171E+03   8.2674377E-02   1.5053997E+01   2.1288835E+03   5.1588297E+04

POINT =  4   MACH NUMBER =  0.0000     DENSITY RATIO =  1.0000E+00     METHOD = K

KFREQ       1./KFREQ        VELOCITY       DAMPING           FREQUENCY          COMPLEX      EIGENVALUE
0.1100     9.0909090E+00   6.4975281E+02  -4.9224150E-01   2.0803311E+00  -1.6744279E+03   7.1930576E+03
0.1100     9.0909090E+00   9.7453589E+02  -2.8433582E-02   3.1201978E+00  -1.6617331E+02   1.1690888E+04
0.1100     9.0909090E+00   1.8861669E+03  -2.0553094E-01   6.0389915E+00  -2.2665554E+03   2.2286127E+04
0.1100     9.0909090E+00   2.6655566E+03  -4.7289357E-02   8.5343847E+00  -7.5525952E+02   3.1959898E+04
0.1100     9.0909090E+00   3.1571689E+03  -3.9091003E-01   1.0108393E+01  -6.7731387E+03   3.5929984E+04
0.1100     9.0909090E+00   4.5606655E+03   1.2136488E-01   1.4602006E+01   3.2908052E+03   5.4428906E+04

POINT =  5   MACH NUMBER =  0.0000     DENSITY RATIO =  1.0000E+00     METHOD = K

KFREQ       1./KFREQ         VELOCITY      DAMPING           FREQUENCY          COMPLEX      EIGENVALUE
0.1000     1.0000000E+01   7.1100360E+02  -5.5938053E-01   2.0694907E+00  -2.0106278E+03   7.7129038E+03
0.1000     1.0000000E+01   1.0549010E+03  -1.4948593E-02   3.0704591E+00  -9.4602501E+01   1.2657751E+04
0.1000     1.0000000E+01   1.9620721E+03  -1.3831225E-01   5.7109265E+00  -1.6090920E+03   2.3378277E+04
0.1000     1.0000000E+01   3.1564470E+03  -3.6192262E-01   9.1873474E+00  -6.3452896E+03   3.6177270E+04
0.1000     1.0000000E+01   3.0453479E+03  -1.1771613E-01   8.8639755E+00  -2.1324919E+03   3.6356176E+04
0.1000     1.0000000E+01   4.8639575E+03   1.4269884E-01   1.4157331E+01   4.1123213E+03   5.7928297E+04

POINT =  6   MACH NUMBER =  0.0000     DENSITY RATIO =  1.0000E+00     METHOD = K

KFREQ           1./KFREQ     VELOCITY      DAMPING           FREQUENCY            COMPLEX    EIGENVALUE
0.0900     1.1111111E+01   7.8175446E+02  -6.3622713E-01   2.0478799E+00  -2.4087664E+03   8.2733408E+03
0.0900     1.1111111E+01   1.1524427E+03  -4.5879173E-05   3.0189331E+00  -3.1723872E-01   1.3829313E+04
0.0900     1.1111111E+01   2.0333984E+03  -6.4582519E-02   5.3266802E+00  -7.8588477E+02   2.4362730E+04
0.0900     1.1111111E+01   3.2243340E+03  -4.6963042E-01   8.4464483E+00  -8.0164155E+03   3.5927914E+04
0.0900     1.1111111E+01   3.5496467E+03  -5.9229746E-02   9.2986374E+00  -1.2587098E+03   4.2539867E+04
0.0900     1.1111111E+01   5.1131235E+03  -2.5528294E-01   1.3394312E+01  -7.5282769E+03   5.9925629E+04

POINT =  7  MACH NUMBER =  0.0000      DENSITY RATIO =  1.0000E+00     METHOD = K

KFREQ           1./KFREQ     VELOCITY      DAMPING           FREQUENCY            COMPLEX    EIGENVALUE
0.0800     1.2500000E+01   8.6312787E+02  -7.2019100E-01   2.0098181E+00  -2.8646790E+03   8.8795234E+03
0.0800     1.2500000E+01   1.2736655E+03   1.2577129E-02   2.9657667E+00   9.6104836E+01   1.5283079E+04
0.0800     1.2500000E+01   2.1041970E+03   9.7037219E-03   4.8996830E+00   1.2250404E+02   2.5249471E+04
0.0800     1.2500000E+01   3.4336306E+03  -5.6644344E-01   7.9953070E+00  -9.7949258E+03   3.7165398E+04
0.0800     1.2500000E+01   4.0859543E+03   1.0565862E-02   9.5142622E+00   2.5901172E+02   4.9029402E+04
0.0800     1.2500000E+01   5.1808037E+03  -2.2965454E-01   1.2063651E+01  -6.9128076E+03   6.0985379E+04

POINT =  8  MACH NUMBER =  0.0000     DENSITY RATIO =  1.0000E+00     METHOD = K

KFREQ           1./KFREQ      VELOCITY     DAMPING           FREQUENCY            COMPLEX    EIGENVALUE
0.0700     1.4285714E+01   9.5593756E+02  -8.0510581E-01   1.9476870E+00  -3.3659946E+03   9.5482207E+03
0.0700     1.4285714E+01   1.4277452E+03   1.4557940E-02   2.9089777E+00   1.2469366E+02   1.7131582E+04
0.0700     1.4285714E+01   2.1785779E+03   8.7926425E-02   4.4387712E+00   1.1438076E+03   2.6067568E+04
0.0700     1.4285714E+01   3.6923875E+03  -6.2787712E-01   7.5231023E+00  -1.1281727E+04   3.9184270E+04
0.0700     1.4285714E+01   4.7511987E+03   1.0976043E-01   9.6803904E+00   3.1056233E+03   5.6759051E+04
0.0700     1.4285714E+01   5.2292749E+03  -2.5029042E-01   1.0654453E+01  -7.5599551E+03   6.1341188E+04
```

Listing 8-10 Output Data for Jet Transport Wing by Strip Theory (Continued)

```
POINT =   9  MACH NUMBER =  0.0000     DENSITY RATIO =  1.0000E+00     METHOD = K

KFREQ          1./KFREQ      VELOCITY     DAMPING          FREQUENCY         COMPLEX      EIGENVALUE
0.0600     1.6666668E+01  1.0600907E+03  -8.7908369E-01   1.8513387E+00  -3.8895288E+03   1.0315609E+04
0.0600     1.6666668E+01  1.6248770E+03  -1.5172217E-02   2.8376794E+00  -1.4789662E+02   1.9496840E+04
0.0600     1.6666668E+01  2.2673284E+03   1.8877667E-01   3.9596546E+00   2.5124709E+03   2.6853520E+04
0.0600     1.6666668E+01  3.9750569E+03  -6.4238346E-01   6.9420252E+00  -1.2322738E+04   4.1982645E+04
0.0600     1.6666668E+01  5.4398892E+03  -2.8827396E-01   9.5002041E+00  -8.9502500E+03   6.3359762E+04
0.0600     1.6666668E+01  5.4874829E+03   2.0974435E-01   9.5833206E+00   6.7222744E+03   6.4797086E+04

POINT =  10  MACH NUMBER =  0.0000     DENSITY RATIO =  1.0000E+00     METHOD = K

KFREQ           1./KFREQ      VELOCITY     DAMPING          FREQUENCY         COMPLEX      EIGENVALUE
0.0500     2.0000000E+01  1.1731140E+03  -9.2128611E-01   1.7072686E+00  -4.3906812E+03   1.1245871E+04
0.0500     2.0000000E+01  1.8484214E+03  -1.0854372E-01   2.6900640E+00  -1.1950244E+03   2.2083893E+04
0.0500     2.0000000E+01  2.4442273E+03   3.4569389E-01   3.5571585E+00   4.7234243E+03   2.8120604E+04
0.0500     2.0000000E+01  4.2461313E+03  -5.9229535E-01   6.1795239E+00  -1.2486703E+04   4.5584203E+04
0.0500     2.0000000E+01  5.6875884E+03  -2.8833213E-01   8.2773209E+00  -9.3594961E+03   6.6244016E+04
0.0500     2.0000000E+01  6.3592007E+03  -3.2859224E-01   9.2547398E+00  -1.1757339E+04   7.3444063E+04

POINT = 11  MACH NUMBER =  0.0000     DENSITY RATIO =  1.0000E+00     METHOD = K

KFREQ          1./KFREQ     VELOCITY      DAMPING          FREQUENCY         COMPLEX      EIGENVALUE
0.0400     2.5000000E+01  1.2868806E+03  -8.9883047E-01   1.4982692E+00  -4.7671958E+03   1.2435130E+04
0.0400     2.5000000E+01  2.0593215E+03  -2.2574347E-01   2.3975947E+00  -2.7038494E+03   2.4256457E+04
0.0400     2.5000000E+01  2.8123025E+03   5.1323569E-01   3.2742634E+00   7.4764253E+03   3.0941035E+04
0.0400     2.5000000E+01  4.4346304E+03  -4.7134125E-01   5.1630821E+00  -1.1056445E+04   4.9389918E+04
0.0400     2.5000000E+01  5.8831919E+03  -2.5362745E-01   6.8495908E+00  -8.6101797E+03   6.8971156E+04
0.0400     2.5000000E+01  6.6293276E+03  -3.7671489E-01   7.7182899E+00  -1.3787740E+04   7.5710766E+04

POINT = 12  MACH NUMBER =  0.0000     DENSITY RATIO =  1.0000E+00     METHOD = K

KFREQ          1./KFREQ     VELOCITY      DAMPING          FREQUENCY         COMPLEX      EIGENVALUE
0.0010     9.9999994E+02  1.4217333E+03  -2.5042098E-02   4.1381840E-02  -2.1353542E+02   1.7056789E+04
0.0010     9.9999994E+02  2.8758196E+03  -2.2423953E-02   8.3705366E-02  -3.8680191E+02   3.4503332E+04
0.0010     9.9999994E+02  4.4903926E+03  -1.1577159E-02   1.3070011E-01  -3.1188980E+02   5.3882004E+04
0.0010     9.9999994E+02  6.0116860E+03  -9.1055688E-03   1.7497981E-01  -3.2842191E+02   7.2137992E+04
0.0010     9.9999994E+02  8.1402681E+03   1.2691311E-02   2.3693562E-01  -6.1980164E+02   9.7677313E+04
0.0010     9.9999994E+02  5.4302238E+04   3.4501605E-02   1.5805541E+00   1.1232731E+04   6.5133625E+05

POINT = 13  MACH NUMBER =  0.0000     DENSITY RATIO =  1.0000E+00     METHOD = K

KFREQ        1./KFREQ       VELOCITY      DAMPING          FREQUENCY       COMPLEX        EIGENVALUE
0.0001     1.0000000E+04  1.4197896E+03  -3.0325665E-03   4.1325260E-03  -2.5833488E+01   1.7037416E+04
0.0001     1.0000000E+04  2.8725632E+03  -2.7793243E-03   8.3610583E-03  -4.7902473E+01   3.4470656E+04
0.0001     1.0000000E+04  4.4856504E+03  -1.7072423E-03   1.3056207E-02  -4.5948467E+01   5.3827746E+04
0.0001     1.0000000E+04  6.0053628E+03  -1.5231079E-03   1.7479576E-02  -5.4880810E+01   7.2064289E+04
0.0001     1.0000000E+04  8.1311860E+03  -1.8892016E-03   2.3667125E-02  -9.2168495E+01   9.7574102E+04
0.0001     1.0000000E+04  6.7762256E+05   3.0369260E-03   1.9723294E+00   1.2347267E+04   8.1314425E+06
```

Flutter Analysis of Jet Transport Wing/Aileron by Strip Theory (Example HA145D)

In this example, an aileron is added to the BAH wing of Example HA145C (p. 444). Strip Theory is used again, but with an approximation to the circulation function, and the PK-method is used. The aileron is assumed to have a stiff actuator and a high aileron frequency (an uncoupled frequency of 60 Hz) so that it does not couple substantially with the wing. The aileron inertial characteristics are given on the CONM1 entry to illustrate inclusion of static unbalance, although the example aileron is balanced (as it should be). The SPLINE3 entry illustrates the method of including a control surface in Strip Theory. The correction factors $[W_{KK}]$ shown in (2-21)) are introduced into the theoretical oscillatory aerodynamic coefficients via DMI entries that provide the factors; a 50% reduction in control surface hinge moment is illustrated. The PK-Flutter method is used for comparison to Rodden, Harder, and Bellinger (1979, Figs. 17-19 [Reference 50]).

The aileron characteristics are provided by the input data BAH_AILERON.DAT, shown previously in Listing 7-5. The CAERO4 1001 and PAERO4 entries, along with the AEFACT 1 and AEFACT 2 entries, provide the Strip Theory aerodynamics for nine strips on the wing: five inboard of the aileron, three across the aileron, and one outboard, as shown in Figure 8-8. The PAERO4 entry specifies no Prandtl-Glauert compressibility correction and three terms in the approximate circulation function with coefficients on AEFACT 2. The PAERO4 entry also specifies the control surface geometry on each strip, (there is no control surface on Strips 1 through 5, and 9) and a control surface on Strips 6 through 8 with a 75% hinge line and 25% chord without a gap. The theoretical oscillatory aerodynamic loads are modified by factors on DMI entries. Unit factors are input on each strip for lift and pitching moment and a factor of 0.50 is input to reduce the control surface hinge moments on Strips 6 through 8. Three SPLlNE3 entries provide the control surface connection for the three strips with the control surface. SPLlNE3 151 specifies the relative angle on the sixth strip (UKID = 1006) on panel CAER04 1001 via the code COMP = 6 to be equal to the negative rotation (R2) of GRID 12. SPLINE3 152 and 153 specify the angle on the seventh and eighth strips.

The vibration analysis uses the modified Givens method and requests 11 modes: 10 for the wing and one for the aileron. The parameter PARAM,LMODES selects all eleven modes for the modal formulation of the flutter equations. The PK-method is specified on FLUTTER 40 for sea-level density and Mach zero; the tabulation of velocities on FLFACT 4 lists all values as positive so no eigenvectors will be obtained for the six roots that are requested. ENDDATA is the last entry in the input Bulk Data Section.

Case Control Commands

The Case Control Section includes the title, subtitle, label, ECHO = BOTH, SPC = 1 for the additional fuselage constraints, SDAMP = 2000 for the structural damping, MPC = 1 for the control surface rotation, METHOD = 10 for the vibration analysis, SVEC = ALL to print the vibration modes of the a-set grid points, and FLUTTER = 40 for the PK-flutter method. SDISP(PLOT) = ALL, and DISP(PLOT) = 10 save the data for subsequent plotting but do not print them, and BEGIN BULK completes the Case Control Section.

The Executive Control Section includes ID MSC, HA145D, TIME 5, and SOL 145. CEND concludes the Executive Control Section.

Output

The input data are shown in Listing 8-11 and the Sorted Bulk Data entries follow in Listing 8-12. Selected output data are presented in Listing 8-13. Highlights of the output are discussed as follows.

The statically balanced (and massless) aileron does not affect any of the wing frequencies, and the coupled wing/aileron frequency is 59.993 Hz. The flutter solutions are almost identical to the case without the aileron [Rodden, Harder, and Bellinger (1979, Figs. 17-19) [Reference 50]] as expected because of the high aileron frequency, the aileron complete balance, and the reduction in the aileron aerodynamic hinge moment coefficients. In the Flutter Summaries, Points 1 and 2 are of primary interest. Point 1 gives the solution for the stable bending mode until it transitions to an aerodynamic lag root that goes unstable at the divergence speed of $V = 1419.9\ \text{ft/s}$. This is the expected divergence speed. The appearance of the aerodynamic lag root was not recognized by Rodden, Harder, and Bellinger (1979) [Reference 50] but is explained by Rodden and Bellinger (1982a) [Reference 44]. Point 2 is the coupled torsion mode that goes unstable at the lowest flutter speed of $V = 1133\ \text{ft/s}$ (by linear interpolation), as before. The flutter speed is slightly lower than that obtained ($1152\ \text{ft/s}$) in the previous Example HA145C of (p. 444) because of the different representations of the circulation function, not because of differences between the K- and PK-methods of flutter analysis.

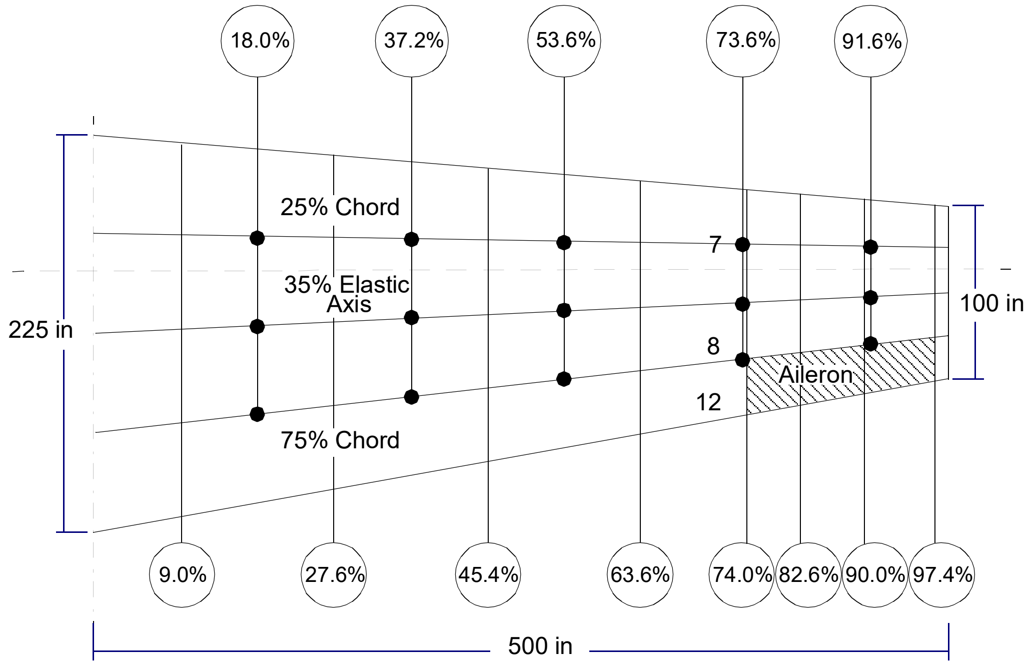

Figure 8-8 BAH Wing and Aileron and Aerodynamic Strip Idealization

Listing 8-11 Input Files for Jet Transport Wing/Aileron by Strip Theory

```
    N A S T R A N    E X E C U T I V E    C O N T R O L    D E C K    E C H O


ID MSC, HA145D
$$$$$$$$    HANDBOOK FOR AEROELASTIC ANALYSIS EXAMPLE H145D     $$$$$$$$
$                                                                      $
$       MODEL DESCRIPTION       BAH JET TRANSPORT WING EXAMPLE         $
$                               CANTILEVERED WING WITH BALANCED        $
$                               CONTROL SURFACE                        $
$                                                                      $
$       SOLUTION                PK FLUTTER ANALYSIS METHOD USING       $
$                               STRIP THEORY AERODYNAMICS WITH THE     $
$                               W.P.JONES APPROXIMATION TO THE         $
$                               THEODORSEN FUNCTION AT MACH NO. 0.     $
$                                                                      $
$       OUTPUT                  TABULATED MODAL DEFLECTIONS PLUS       $
$                               X-Y PLOTS OF V-G FLUTTER DATA          $
$                                                                      $
$$$$$$$$                                                        $$$$$$$$
TIME 10 $ TIME IN CPU MINUTES
SOL  145 $ FLUTTER ANALYSIS
CEND


EXAMPLE HA145D: BAH JET TRANSPORT WING WITH CONTROL SURFACE                                                           PAGE     2
 CANTILEVERED, W.P.JONES STRIP THEORY AT MACH NO. 0.0

 PK FLUTTER METHOD
                              C A S E    C O N T R O L    D E C K    E C H O
            CARD
            COUNT
             1      TITLE = EXAMPLE HA145D: BAH JET TRANSPORT WING WITH CONTROL SURFACE
             2      SUBTI = CANTILEVERED, W.P.JONES STRIP THEORY AT MACH NO. 0.0
             3      LABEL = PK FLUTTER METHOD
             4        ECHO        = BOTH
             5        SPC         = 1     $ FUSELAGE CONSTRAINT
             6        SDAMP       = 2000  $ STRUCTURAL DAMPING
             7        MPC         = 1     $ CONTROL SURFACE RELATIVE MOTION
             8        METHOD      = 10    $ MODIFIED GIVENS FOR VIBRATION ANALYSIS
             9        SVEC        = ALL   $ PRINT VIBRATION MODES
            10        FMETHOD     = 40    $ PK-FLUTTER METHOD
            11      $---BE CAREFUL WITH EIGENVECTOR TABULATIONS:  THE SDISP COMMAND PRINTS
            12      $   ONE MODAL EIGENVECTOR PER PAGE FOR EACH EIGENVALUE AND FOR ALL THE
            13      $   VALUES OF REDUCED FREQUENCY; THE DISP COMMAND PRINTS THE CORRESPONDING
            14      $   GRID DISPLACEMENTS ONE SET PER PAGE
            15        SDISP(PLOT) = ALL   $ PLOT AND SAVE ALL MODAL PARTICIPATION FACTORS
            16        SET 10   = 1 THRU 5000
            17        DISP(PLOT)  = 10    $ PLOT AND SAVE STRUCTURAL DISPLACEMENTS IN SET 10
            18      OUTPUT(XYOUT)
            19        CSCALE 2.0
            20        PLOTTER NASTRAN
            21        CURVELINESYMBOL = -6
            22        YTTITLE = DAMPING  G
            23        YBTITLE =FREQUENCY  F HZ
            24        XTITLE  = VELOCITY  V (FT/SEC)
            25        XMIN  =     0.
            26        XMAX  = 2500.
            27        YMIN =  -.6
            28        YTMAX =  +.1
            29        YBMIN =   0.
            30        YBMAX =  15.
            31        XTGRID LINES = YES
            32        XBGRID LINES = YES
            33        YTGRID LINES = YES
            34        YBGRID LINES = YES
            35        UPPER TICS  = -1
            36        TRIGHT TICS = -1
            37        BRIGHT TICS = -1
            38        XYPLOT VG / 1(G,F)  2(G,F)  3(G,F)  4(G,F)  5(G,F)  6(G,F)  7(G,F),
            39                    8(G,F)  9(G,F) 10(G,F) 11(G,F) 12(G,F) 13(G,F) 14(G,F),
            40                   15(G,F) 16(G,F) 17(G,F) 18(G,F) 19(G,F)
            41        CURVELINESYMBOL = -6
            42        YTTITLE = DAMPING  G
            43        YBTITLE =FREQUENCY  F HZ
            44        XTITLE  = VELOCITY  V (FT/SEC)
            45        XMIN  =     0.
            46        XMAX  = 1600.
            47        YTMIN =  -1.7
            48        YTMAX =   +.1
            49        YBMIN =   0.
```

Listing 8-11 Input Files for Jet Transport Wing/Aileron by Strip Theory (Continued)

```
       YBMAX =   2.5
       XTGRID LINES = YES
       XBGRID LINES = YES
       YTGRID LINES = YES
       YBGRID LINES = YES
       UPPER TICS  = -1
       TRIGHT TICS = -1
       BRIGHT TICS = -1
       XYPLOT VG / 1(G,F)  2(G,F)  3(G,F)  4(G,F)  5(G,F)  6(G,F)  7(G,F),
                   8(G,F)  9(G,F) 10(G,F) 11(G,F) 12(G,F) 13(G,F) 14(G,F),
                  15(G,F) 16(G,F) 17(G,F) 18(G,F) 19(G,F)
     BEGIN BULK
```

```
EXAMPLE HA145D: BAH JET TRANSPORT WING WITH CONTROL SURFACE                                                    PAGE     4
 CANTILEVERED, W.P.JONES STRIP THEORY AT MACH NO. 0.0

 PK FLUTTER METHOD
                                        I N P U T   B U L K   D A T A   D E C K   E C H O

                         .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                         $*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
                         $                                                                        $
                         $        THE ANNOTATIONS IN THIS INPUT DECK ARE INTENDED TO              $
                         $        EXPLAIN THE DATA ON THE CARD IMAGES FOR THIS SPECIFIC           $
                         $        EXAMPLE WITHOUT REFERENCE TO THE VARIOUS MANUALS WHERE          $
                         $        MORE GENERAL DESCRIPTIONS WILL BE FOUND.                        $
                         $                                                                        $
                         $*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
                         $                                                                        $
                         INCLUDE BAH_STRUCT.DAT
                         $                                                                        $
                         INCLUDE BAH_AILERON.DAT
                         $                                                                        $
                         INCLUDE BAH_MASS.DAT
                         $                                                                        $
                         $                    * * STRUCTURAL CONSTRAINTS * *                      $
                         $                                                                        $
                         $        THE SPC ENTRY DEFINES SETS OF SINGLE-POINT CONSTRAINTS          $
                         $        AND ENFORCED DISPLACEMENTS.  IT LISTS THE ID, GRID POINT        $
                         $        NO., CONSTRAINED DOFS AND VALUE OF AN ENFORCED DISPLACE-        $
                         $        MENT.                                                           $
                         $                                                                        $
                         $       SID     G       C       D
                         SPC     1       11      345
                         $                                                                        $
                         $                      * * STRUCTURAL DAMPING * *                        $
                         $                                                                        $
                         $        THE PARAMETER KDAMP DETERMINES THE MANNER OF INCLUSION          $
                         $        OF STRUCTURAL DAMPING IN EQUATIONS OF MOTION (SEE HANDBOOK      $
                         $        FOR DYNAMIC ANALYSIS, SECT. 3.2.2).  IF SET TO -1, MODAL        $
                         $        DAMPING IS PUT INTO COMPLEX STIFFNESS MATRIX AS STRUCTURAL      $
                         $        DAMPING.                                                        $
                         $                                                                        $
                         $       N       V1      V2
                         PARAM   KDAMP   +1
                         $                                                                        $
                         $        THE TABDMP1 ENTRY DEFINES MODAL DAMPING AS A TABULAR            $
                         $        FUNCTION OF FREQUENCY.  THE DAMPING LEVELS ARE LINEAR           $
                         $        BETWEEN THE FREQUENCY AND DAMPING PAIRS AND ARE EXTRAP-         $
                         $        OLATED OUTSIDE THE TABULATED FREQUENCY RANGE.                   $
                         $                                                                        $
                         $       ID
                         TABDMP1 2000                                                            +T2000
                         $       F1      G1      F2      G2      ETC             ENDT
                         +T2000  0.      0.0     10.     0.0     ENDT
                         $                                                                        $
                         $                      * * * AERODYNAMIC DATA * * *                      $
                         $                                                                        $
                         $                           (LB-IN-SEC SYSTEM)                           $
                         $                                                                        $
                         $                        * * ELEMENT GEOMETRY * *                        $
                         $                                                                        $
```

Listing 8-11 Input Files for Jet Transport Wing/Aileron by Strip Theory (Continued)

```
$        THE AERO ENTRY SPECIFIES THE AERO COORDINATE SYSTEM, THE      $
$        REFERENCE LENGTHS PLUS SYMMETRY KEYS.  SYMXZ = 1 INDICATES    $
$        THAT THE MODEL IS MOUNTED WITH A ROOT REFLECTION PLANE;       $
$        SYMXY = 0 INDICATES THAT THE MODEL IS MOUNTED FAR ENOUGH      $
$        FROM THE FLOOR SO THAT REFLECTION EFFECTS ARE NEGLIGIBLE.     $
$        NOTE THAT THE THE DIMENSIONS OF THE REFERENCE DENSITY OF      $
$        AIR ARE SNAILS PER CUBIC INCH, NOT POUNDS PER CUBIC INCH.     $
$                                                                      $
$       ACSID   VELOCITY REFC    RHOREF  SYMXZ   SYMXY
AERO    1               131.232 1.1468-7  1
$                                                                      $
$        THIS CORD2R ENTRY DEFINES THE AERO COORDINATE SYSTEM          $
$        FLAGGED BY THE AERO ENTRY.  LISTED ARE THE ORIGIN, A          $
$        POINT ALONG THE Z AXIS AND A POINT IN THE X-Z PLANE,          $
$        ALL IN THE RID COORDINATE SYSTEM.  NOTE THAT IN THIS          $
$        COORDINATE SYSTEM THE UPSIDE DOWN AND BACKWARDS STRUC-        $
$        TURE WILL FLY UPSIDE UP AND FORWARD.                          $
$                                                                      $
$       CID     RID     A1      A2      A3      B1      B2      B3
CORD2R  1               0.      0.      0.      0.      0.      -1.     +C1
$       C1      C2      C3
+C1     -1.     0.      0.
$                                                                      $
$        THE CAERO4 ENTRY IS USED TO SPECIFY STRIP THEORY AERO.        $
$        PID IDENTIFIES A PAERO4 ENTRY WHERE THE ELEMENT PROPERTIES    $
$        ARE GIVEN, CP DEFAULTS TO THE BASIC COORDINATE SYSTEM,        $
$        NSPAN WOULD BE THE NUMBER OF EQUAL SPAN STRIPS, HOWEVER       $
$        LSPAN SPECIFIES THE AEFACT ENTRY WHERE THE UNEQUAL STRIP      $
$        WIDTHS ARE DEFINED.  THE CONTINUATION ENTRY DEFINES THE       $
$        INBD AND OUTBD LEADING EDGE POINTS AND THE CHORDS.            $
$                                                                      $
$       EID     PID     CP      NSPAN   LSPAN
CAERO4  1001    1001    0       0       1                               +BAH
$       X1      Y1      Z1      X12     X4      Y4      Z4      X43
+BAH    78.75   0.0     0.0     225.0   35.0    500.0   0.0     100.0
$                                                                      $
$        THIS AEFACT ENTRY GIVES THE EDGES OF THE STRIPS IN PERCENT    $
$        OF SPAN.                                                      $
$                                                                      $
$       SID     D1      D2      D3      ETC
AEFACT  1       .0      .09     .276    .454    .636    .74     .826    +AF
+AF     .90     .974    1.0
$                                                                      $
$        THE PAERO4 ENTRY DEFINES PROPERTIES OF THE STRIP ELEMENTS     $
$        FOR STRIP THEORY AERODYNAMICS.  IT OFFERS A WIDE VARIETY      $
$        OF OPTIONS.  CLA DEFAULTS TO NO COMPRESSIBILITY CORRECTION    $
$        AND NO CORRECTIONS OF LIFT CURVE SLOPES.  LCLA MUST BE ZERO   $
$        WHEN CLA IS ZERO.  CIRC=2 SPECIFIES AN APPROXIMATE EXPRESSION $
$        FOR THE THEODORSEN CIRCULATION FUNCTION; THE APPOXIMATION     $
$        CONSTANTS ARE LISTED ON AN AEFACT ENTRY SPECIFIED BY LCIRC.   $
$        DOC, CAOC, AND GAPOC ARE REQUIRED EVEN THOUGH A STRIP HAS NO  $
$        CONTROL SURFACE.  THESE ARE THE DISTANCE FROM THE QUARTER-    $
$        CHORD TO THE HINGE LINE, THE CONTROL SURFACE CHORD, AND THE   $
$        GAP BETWEEN THE PRIMARY SURFACE AND THE CONTROL SURFACE, ALL  $
$        EXPRESSED AS FRACTIONS OF THE LOCAL CHORD.  CAOC=0.0 SPECIFIES $
$        NO CONTROL SURFACE.                                           $
$                                                                      $
$       PID     CLA     LCLA    CIRC    LCIRC   DOC1    CAOC1   GAPOC1
PAERO4  1001    0       0       2       2       0.0     0.0     0.0     +PA41
+PA41   0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     +PA42
+PA42   0.0     0.0     0.0     0.0     0.50    0.25    0.0     0.50    +PA43
+PA43   0.25    0.0     0.50    0.25    0.0     0.0     0.0     0.0
$                                                                      $
$        THE AEFACT ENTRY IS A UTILITY ENTRY USED TO SPECIFY LISTS OF  $
$        NUMBERS.  THESE ARE IDENTIFIED BY THE LCIRC FIELD OF THE      $
$        PAERO4 ENTRY AND ARE THE W.P.JONES CONSTANTS FOR THE          $
$        APPROXIMATE CIRCULATION FUNCTION.                             $
$                                                                      $
AEFACT  2       0.0     1.0     -0.165  0.041   -0.335  0.320
$                                                                      $
$                 * AERODYNAMIC CORRECTION FACTORS *                   $
$                                                                      $
$        THE DMI ENTRIES PROVIDE FOR DIRECT MATRIX INPUT BY THE USER.  $
$        IN THIS CASE, THEY ARE CORRECTION FACTORS TO                  $
$        MODIFY THE THEORETICAL OSCILLATORY AERODYNAMIC COEFFICIENTS   $
$        TO AGREE WITH EXPERIMENTAL DATA.                              $
$                                                                      $
$       NAME    "0"     FORM    TIN     TOUT            M       N
DMI     WTFACT  0       2       1                       21      21
$ 1ST STRIP
$       NAME    J       I1      A(I1,J) A(I1+1,J)       ETC.
```

Listing 8-11 Input Files for Jet Transport Wing/Aileron by Strip Theory (Continued)

```
DMI     WTFACT  1       1       1.0
DMI     WTFACT  2       2       1.0
$ 2ND STRIP
DMI     WTFACT  3       3       1.0
DMI     WTFACT  4       4       1.0
$ 3RD STRIP
DMI     WTFACT  5       5       1.0
DMI     WTFACT  6       6       1.0
$ 4TH STRIP
DMI     WTFACT  7       7       1.0
DMI     WTFACT  8       8       1.0
$ 5TH STRIP
DMI     WTFACT  9       9       1.0
DMI     WTFACT  10      10      1.0
$ 6TH STRIP
DMI     WTFACT  11      11      1.0
DMI     WTFACT  12      12      1.0
DMI     WTFACT  13      13      0.50
$ 7TH STRIP
DMI     WTFACT  14      14      1.0
DMI     WTFACT  15      15      1.0
DMI     WTFACT  16      16      0.50
$ 8TH STRIP
DMI     WTFACT  17      17      1.0
DMI     WTFACT  18      18      1.0
DMI     WTFACT  19      19      0.50
$ 9TH STRIP
DMI     WTFACT  20      20      1.0
DMI     WTFACT  21      21      1.0
$                                                                       $
$               * * SPLINE FIT ON THE LIFTING SURFACES * *              $
$                                                                       $
$                     * BEAM SPLINE FIT ON THE WING *                   $
$                                                                       $
$        THE SPLINE2 ENTRY SPECIFIES A BEAM SPLINE FOR INTERPOLAT-      $
$        ION OVER THE REGION OF THE CAERO ENTRY (ID1 AND ID2 ARE        $
$        THE FIRST AND LAST BOXES IN THIS REGION).  SETG REFERS         $
$        TO A SET1 ENTRY WHERE THE STRUCTURAL GRID POINTS ARE           $
$        DEFINED.  DZ AND DTOR ARE SMOOTHING CONSTANTS FOR LINEAR       $
$        ATTACHMENT AND TORSIONAL FLEXIBILITIES.  DTHX AND DTHY         $
$        ARE ROTATIONAL ATTACHMENT FLEXIBILITIES. CID IDENTIFIES        $
$        THE SPLINE AXIS.                                               $
$                                                                       $
$       EID     CAERO   ID1     ID2     SETG    DZ      DTOR    CID
SPLINE2 100     1001    1002    1009    14      .0      1.0     0       +SP100
$       DTHX    DTHY
+SP100  -1.0    -1.0
$                                                                       $
$        THE SET1 ENTRY DEFINES THE SETS OF STRUCTURAL GRID POINTS      $
$        TO BE USED BY THE BEAM SPLINE FOR INTERPOLATION.               $
$                                                                       $
$       SID     G1      G2      G3      G4      G5      G6
SET1    14      1       THRU    11
$
$        THE SPLINE3 ENTRY DEFINES A CONSTRAINT EQUATION FOR AEROELASTIC $
$        PROBLEMS; IT IS PARTICULARLY USEFUL FOR CONTROL SURFACE        $
$        CONSTRAINTS.  THE CAERO FIELD IS ID OF MACRO-ELEMENT ON WHICH  $
$        THE ELEMENT TO BE INTERPOLATED LIES; UKID FIELD IS ID OF UK    $
$        POINT, that is, THE BOX NUMBER; COMP IS COMPONENT OF MOTION TO BE $
$        INTERPOLATED; GI IS ID OF INDEPENDENT GRID POINT; CI IS        $
$        COMPONENT TO BE USED; AI IS COEFFICIENT IN CONSTRAINT          $
$        RELATIONSHIP.                                                  $
$                                                                       $
$       EID     CAERO   UKID    COMP    G1      C1      A1      ---     +ETC
SPLINE3 151     1001    1006    6       12      5       -1.0
SPLINE3 152     1001    1007    6       12      5       -1.0
SPLINE3 153     1001    1008    6       12      5       -1.0
$                                                                       $
$                  * * * SOLUTION SPECIFICATIONS * * *                  $
$                                                                       $
$                    * * AERODYNAMIC CONDITIONS * *                     $
$                                                                       $
$        ALL COMBINATIONS OF MACH NUMBER AND REDUCED FREQUENCY LISTED   $
$        ON THE MKAERO1 ENTRY AND ITS CONTINUATION ENTRY WILL BE USED   $
$        TO GENERATE GENERALIZED AERO FORCE MATRICES.  IF MORE THAN     $
$        EIGHT MACH NO.S OR REDUCED FREQUENCIES ARE REQUIRED A SECOND   $
$        MKAERO1 ENTRY IS NECESSARY.                                    $
$                                                                       $
$        M1     M2      M3      ETC
MKAERO1 0.0                                                             +MK1
$        K1     K2      K3      K4      ETC
```

Listing 8-11   Input Files for Jet Transport Wing/Aileron by Strip Theory (Continued)

```
+MK1    0.001   0.02    0.04    0.06    0.08    0.10    0.12    0.20
MKAERO1 0.0                                                             +MK2
+MK2    0.50    1.0     1.5
$                                                                       $
$                      * * SOLUTION PARAMETERS * *                      $
$                                                                       $
$        THE FLUTTER ENTRY DEFINES THE METHOD OF SOLUTION, IDENTIFIES   $
$        THE FLFACT ENTRIES THAT FOLL0W, SPECIFIES THE INTERPOLATION    $
$        METHOD, THE NUMBER OF ROOTS DESIRED IN THE OUTPUT AND THE      $
$        CRITERION FOR CONVERGENCE (DEFAULT IS 10-3).                   $
$                                                                       $
$       SID     METHOD  DENS    MACH    VEL     IMETH   NVALUE  EPS     $
FLUTTER 40      PK      1       2       4       L       6
$                                                                       $
$        FLFACT ENTRIES ARE USED TO SPECIFY DENSITY RATIOS, MACH NO.S   $
$        AND REDUCED FREQUENCIES/VELOCITIES FOR FLUTTER ANALYSES.       $
$                                                                       $
$       SID     F1      F2      F3      F4      F5      F6      F7      $
FLFACT  1       1.                                                      DENSITY
FLFACT  2       0.0                                                     MACH NO
FLFACT  4       4800.   6000.   7200.   8400.   9600.   10800.  12000.  +FLF4
+FLF4   12597.6 12598.8 13200.  14400.  15600.  17038.8 18000.  19200.  +FLF4A
+FLF4A  20400.  21600.  22800.  24000.  25200.                           RFREQ
$                                                                       $
$        THE PARAM,LMODES,N ENTRY SPECIFIES THAT N MODES ARE TO BE      $
$        USED IN THE FLUTTER ANALYSIS.                                  $
$                                                                       $
$       N       V1      V2
PARAM   LMODES  11
PARAM   OPGTKG  1
$                                                                       $
$        THE PARAM,VREF,C ENTRY SPECIFIES A CONVERSION FACTOR TO BE     $
$        USED TO CONVERT THE DIMENSIONS OF THE OUTPUT VELOCITIES BY     $
$        DIVIDING BY C, IN THIS CASE BY 12.0 IN/FT TO PRINT VEL-        $
$        OCITIES IN FT/SEC RATHER THAN IN/SEC.                          $
$                                                                       $
PARAM   VREF    12.0
$                                                                       $
$                    * * EIGENSOLUTION PARAMETERS * *                   $
$                                                                       $
$        THE EIGR ENTRY SPECIFIES THE METHOD OF EXTRACTING THE EIGEN-   $
$        SOLUTIONS OF THE STRUCTURE IN A VACUUM; IN THIS CASE THE       $
$        MODIFIED GIVENS METHOD.  ELEVEN MODES ARE DESIRED, NORMAL-     $
$        IZED ON THE MAXIMUM DISPLACEMENTS.                             $
$                                                                       $
$       SID     METHOD  F1      F2              ND                      $
EIGR    10      MGIV                            11                      +EIGR
$       NORM    G       C                                               $
+EIGR   MAX
$                                                                       $
ENDDATA

INPUT BULK DATA CARD COUNT =     448
```

Listing 8-12 Sorted Bulk Data Entries for Jet Transport Wing/Aileron by Strip Theory

```
EXAMPLE HA145D: BAH JET TRANSPORT WING WITH CONTROL SURFACE              APRIL   1, 1993  MSC/NASTRAN   3/31/93   PAGE    13
 CANTILEVERED, W.P.JONES STRIP THEORY AT MACH NO. 0.0

 PK FLUTTER METHOD

                                        S O R T E D   B U L K   D A T A   E C H O
             CARD
             COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                1-        AEFACT  1       .0      .09     .276    .454    .636    .74     .826    +AF
                2-        +AF     .90     .974    1.0
                3-        AEFACT  2       0.0     1.0     -0.165  0.041   -0.335  0.320
                4-        AERO    1               131.232 1.1468-71
                5-        CAERO4  1001    1001    0       0       1                               +BAH
                6-        +BAH    78.75   0.0     0.0     225.0   35.0    500.0   0.0     100.0
                7-        CELAS2  3       5142661.12      5
                8-        CMASS2  121     5248.7  1       3
                9-        CMASS2  122     134.9   1       3       2       3
               10-        CMASS2  123     790.3   2       3
               11-        CMASS2  341     9727.   3       3
               12-        CMASS2  342     11005.  3       3       4       3
               13-        CMASS2  343     473.    4       3
               14-        CMASS2  561     3253.6  5       3
               15-        CMASS2  562     -139.7  5       3       6       3
               16-        CMASS2  563     946.3   6       3
               17-        CMASS2  781     2617.8  7       3
               18-        CMASS2  782     21.     7       3       8       3
               19-        CMASS2  783     782.3   8       3
               20-        CMASS2  9101    494.8   9       3
               21-        CMASS2  9102    -7.3    9       3       10      3
               22-        CMASS2  9103    185.2   10      3
               23-        CONM1   1       11                                                      +51
               24-        +51     17400.                          4.37+7                          +52
               25-        +52             4.35+09
               26-        CONM1   2       12                                                      +AIL1
               27-        +AIL1   0.0                                                     0.0     +AIL2
               28-        +AIL2           13970.5
               29-        CORD2R  1               0.      0.      0.      0.      0.      -1.     +C1
               30-        +C1     -1.     0.      0.
               31-        DMI     WTFACT  0       2       1                       21      21
               32-        DMI     WTFACT  1       1       1.0
               33-        DMI     WTFACT  2       2       1.0
               34-        DMI     WTFACT  3       3       1.0
               35-        DMI     WTFACT  4       4       1.0
               36-        DMI     WTFACT  5       5       1.0
               37-        DMI     WTFACT  6       6       1.0
               38-        DMI     WTFACT  7       7       1.0
               39-        DMI     WTFACT  8       8       1.0
               40-        DMI     WTFACT  9       9       1.0
               41-        DMI     WTFACT  10      10      1.0
               42-        DMI     WTFACT  11      11      1.0
               43-        DMI     WTFACT  12      12      1.0
               44-        DMI     WTFACT  13      13      0.50
               45-        DMI     WTFACT  14      14      1.0
               46-        DMI     WTFACT  15      15      1.0
               47-        DMI     WTFACT  16      16      0.50
               48-        DMI     WTFACT  17      17      1.0
               49-        DMI     WTFACT  18      18      1.0
               50-        DMI     WTFACT  19      19      0.50
               51-        DMI     WTFACT  20      20      1.0
               52-        DMI     WTFACT  21      21      1.0
               53-        EIGR    10      MGIV                            11                      +EIGR
               54-        +EIGR   MAX
               55-        FLFACT  1       1.                                                      DENSITY
               56-        FLFACT  2       0.0                                                     MACH NO
               57-        FLFACT  4       4800.   6000.   7200.   8400.   9600.   10800.  12000.  +FLF4
               58-        +FLF4   12597.6 12598.8 13200.  14400.  15600.  17038.8 18000.  19200.  +FLF4A
               59-        +FLF4A  20400.  21600. 22800.  24000.  25200.                           RFREQ
               60-        FLUTTER 40      PK      1       2       4       L       6
               61-        GENEL   432             1       3       2       3       3       3       +01
               62-        +01     4       3       5       3       6       3       7       3       +02
               63-        +02     8       3       9       3       10      3                       +03
               64-        +03     UD              11      3       11      4       11      5       +04
               65-        +04     11      6                                                       +05
```

Listing 8-12 Sorted Bulk Data Entries for Jet Transport Wing/Aileron by Strip Theory (Continued)

```
+05     Z       8.7172-61.3361-61.2778-56.2720-61.6251-51.0492-52.0478-5+06
+06     1.5630-52.4285-52.0403-53.0861-56.2720-63.2297-51.0492-53.3529-5+07
+07     1.5630-53.5021-52.0257-53.5785-52.7732-51.5726-54.8255-53.7628-5+08
+08     7.3284-56.4338-59.5810-58.8378-56.3749-53.7628-58.0136-56.4338-5+09
+09     1.0012-48.8378-51.1811-41.2758-41.1344-41.9350-41.8160-42.5283-4+10
+10     2.4294-41.6999-41.8160-42.2920-42.4294-42.8249-43.6862-43.5052-4+11
+11     5.2675-45.1171-44.2292-45.1171-45.7187-48.4840-48.2340-49.2340-4+12
+12     S       1.0     90.0    -20.25  45.0    1.0     90.0    81.0    +13
+13     45.0    1.0     186.0   -17.85  141.0   1.0     186.0   71.4    +14
+14     141.0   1.0     268.0   -15.80  223.0   1.0     268.0   63.2    +15
+15     223.0   1.0     368.0   -13.30  323.0   1.0     368.0   53.2    +16
+16     323.0   1.0     458.0   -11.05  413.0   1.0     458.0   44.2    +17
+17     413.0
GRID    1               20.25   90.                     12456
GRID    2               -81.    90.                     12456
GRID    3               17.85   186.                    12456
GRID    4               -71.4   186.                    12456
GRID    5               15.8    268.                    12456
GRID    6               -63.2   268.                    12456
GRID    7               13.3    368.                    12456
GRID    8               -53.2   368.                    12456
GRID    9               11.05   458.                    12456
GRID    10              -44.2   458.                    12456
GRID    11              0.0     0.                      126
GRID    12              -86.45  368.                    1246
MKAERO1 0.0                                                     +MK2
+MK2    0.50    1.0     1.5
MKAERO1 0.0                                                     +MK1
+MK1    0.001   0.02    0.04    0.06    0.08    0.10    0.12    0.20
MPC     1       12      3       -1.0    8       3       1.5             +MPC1
+MPC1           7       3       -0.5    12      5       33.25
PAERO4  1001    0       0       2       2       0.0     0.0     0.0     +PA41
+PA41   0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     +PA42
+PA42   0.0     0.0     0.0     0.0     0.50    0.25    0.0     0.50    +PA43
+PA43   0.25    0.0     0.50    0.25    0.0     0.0     0.0     0.0
PARAM   GRDPNT  11
PARAM   KDAMP   +1
PARAM   LMODES  11
PARAM   OPGTKG  1
PARAM   VREF    12.0
PARAM   WTMASS  .0025907
SET1    14      1       THRU    11
SPC     1       11      345
SPLINE2 100     1001    1002    1009    14      .0      1.0     0       +SP100
+SP100  -1.0    -1.0
SPLINE3 151     1001    1006    6       12      5       -1.0
SPLINE3 152     1001    1007    6       12      5       -1.0
SPLINE3 153     1001    1008    6       12      5       -1.0
TABDMP1 2000                                                    +T2000
+T2000  0.      0.0     10.     0.0     ENDT
ENDDATA

   TOTAL COUNT=       116
```

Listing 8-13 Output for Jet Transport Wing/Aileron by Strip Theory

```
EXAMPLE HA145D: BAH JET TRANSPORT WING WITH CONTROL SURFACE                                                          PAGE    17
 CANTILEVERED, W.P.JONES STRIP THEORY AT MACH NO. 0.0

 PK FLUTTER METHOD
                     O U T P U T   F R O M   G R I D   P O I N T   W E I G H T   G E N E R A T O R

                                          REFERENCE POINT =       11
                                                          M O
               *  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00 *
               *  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00 *
               *  0.000000E+00  0.000000E+00  4.191900E+04  5.128960E+06 -1.642074E+05  0.000000E+00 *
               *  0.000000E+00  0.000000E+00  5.128960E+06  1.350243E+09 -2.381847E+07  0.000000E+00 *
               *  0.000000E+00  0.000000E+00 -1.642074E+05 -2.381847E+07  4.458796E+09  0.000000E+00 *
               *  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00 *
                                                           S
                                    *  1.000000E+00  0.000000E+00  0.000000E+00 *
                                    *  0.000000E+00  1.000000E+00  0.000000E+00 *
                                    *  0.000000E+00  0.000000E+00  1.000000E+00 *
                          DIRECTION
                     MASS AXIS SYSTEM (S)     MASS              X-C.G.        Y-C.G.        Z-C.G.
                             X            0.000000E+00      0.000000E+00  0.000000E+00  0.000000E+00
                             Y            0.000000E+00      0.000000E+00  0.000000E+00  0.000000E+00
                             Z            4.191900E+04      3.917256E+00  1.223541E+02  0.000000E+00
                                                          I(S)
                                    *  7.226942E+08  3.727022E+06  0.000000E+00 *
                                    *  3.727022E+06  4.458153E+09  0.000000E+00 *
                                    *  0.000000E+00  0.000000E+00  0.000000E+00 *
                                                          I(Q)
                                    *  4.458157E+09                             *
                                    *                7.226906E+08               *
                                    *                              0.000000E+00 *
                                                           Q
                                    *  9.977400E-04  9.999995E-01  0.000000E+00 *
                                    * -9.999995E-01  9.977400E-04  0.000000E+00 *
                                    *  0.000000E+00  0.000000E+00  1.000000E+00 *

                                          R E A L   E I G E N V A L U E S
  MODE    EXTRACTION      EIGENVALUE            RADIANS             CYCLES            GENERALIZED         GENERALIZED
   NO.       ORDER                                                                        MASS              STIFFNESS
   1          1        1.637768E+02        1.279753E+01        2.036790E+00        8.160930E+00        1.336571E+03
   2          2        4.982469E+02        2.232145E+01        3.552568E+00        5.525822E+01        2.753224E+04
   3          3        2.092550E+03        4.574440E+01        7.280447E+00        7.079897E+00        1.481504E+04
   4          4        5.402874E+03        7.350424E+01        1.169856E+01        8.652712E+00        4.674951E+04
   5          5        8.742090E+03        9.349915E+01        1.488085E+01        4.002357E+00        3.498896E+04
   6          8        1.766007E+04        1.328912E+02        2.115029E+01        3.883447E+00        6.858195E+04
   7          6        2.398459E+04        1.548696E+02        2.464826E+01        3.597392E+00        8.628196E+04
   8         10        4.211864E+04        2.052283E+02        3.266309E+01        3.142601E+00        1.323621E+05
   9          9        6.020812E+04        2.453734E+02        3.905239E+01        1.016253E+00        6.118669E+04
  10          7        9.183204E+04        3.030380E+02        4.823000E+01        8.617019E+00        7.913184E+05
  11         11        1.420885E+05        3.769462E+02        5.999286E+01        3.619337E+01        5.142661E+06

 EIGENVALUE =  1.637768E+02
     CYCLES =  2.036790E+00         R E A L   E I G E N V E C T O R   N O .          1

 POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
        1      G                                     4.518474E-02
        2      G                                     4.250221E-02
        3      G                                     1.482559E-01
        4      G                                     1.437271E-01
        5      G                                     3.794104E-01
        6      G                                     3.767312E-01
        7      G                                     6.929946E-01
        8      G                                     6.926546E-01
        9      G                                     9.989689E-01
       10      G                                     1.000000E+00
       12      G                                                                   0.0

 EIGENVALUE =  4.982469E+02
     CYCLES =  3.552568E+00         R E A L   E I G E N V E C T O R   N O .          2

 POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
        1      G                                    -1.635563E-01
        2      G                                     5.449901E-01
        3      G                                    -2.796319E-01
        4      G                                     1.000000E+00
        5      G                                    -2.267440E-01
        6      G                                     9.465655E-01
        7      G                                    -1.388892E-01
        8      G                                     8.878612E-01
        9      G                                    -3.973597E-02
       10      G                                     8.224477E-01
       12      G                                                                   0.0
```

Listing 8-13 Output for Jet Transport Wing/Aileron by Strip Theory (Continued)

```
EIGENVALUE =  1.420885E+05
    CYCLES =  5.999286E+01         R E A L   E I G E N V E C T O R   N O .         11

POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
       1      G                                    0.0
       2      G                                    0.0
       3      G                                    0.0
       4      G                                    0.0
       5      G                                    0.0
       6      G                                    0.0
       7      G                                    0.0
       8      G                                    0.0
       9      G                                    0.0
      10      G                                    0.0
      12      G                                                                  1.000000E+00

 MATRIX WTFACT   (GINO NAME 101 ) IS A DB  PREC          21 COLUMN X          21 ROW SQUARE   MATRIX.
COLUMN       1      ROWS      1 THRU      1     --------------------------------------------------
   ROW
     1)    1.0000D+00
COLUMN       2      ROWS      2 THRU      2     --------------------------------------------------
   ROW
     2)    1.0000D+00
COLUMN       3      ROWS      3 THRU      3     --------------------------------------------------
   ROW
     3)    1.0000D+00
COLUMN       4      ROWS      4 THRU      4     --------------------------------------------------
   ROW
     4)    1.0000D+00
COLUMN       5      ROWS      5 THRU      5     --------------------------------------------------
   ROW
     5)    1.0000D+00
COLUMN       6      ROWS      6 THRU      6     --------------------------------------------------
   ROW
     6)    1.0000D+00
COLUMN       7      ROWS      7 THRU      7     --------------------------------------------------
   ROW
     7)    1.0000D+00
COLUMN       8      ROWS      8 THRU      8     --------------------------------------------------
   ROW
     8)    1.0000D+00
COLUMN       9      ROWS      9 THRU      9     --------------------------------------------------
   ROW
     9)    1.0000D+00
COLUMN      10      ROWS     10 THRU     10     --------------------------------------------------
   ROW
    10)    1.0000D+00
COLUMN      11      ROWS     11 THRU     11     --------------------------------------------------
   ROW
    11)    1.0000D+00
COLUMN      12      ROWS     12 THRU     12     --------------------------------------------------
   ROW
    12)    1.0000D+00
COLUMN      13      ROWS     13 THRU     13     --------------------------------------------------
   ROW
    13)    5.0000D-01
COLUMN      14      ROWS     14 THRU     14     --------------------------------------------------
   ROW
    14)    1.0000D+00
COLUMN      15      ROWS     15 THRU     15     --------------------------------------------------
   ROW
    15)    1.0000D+00
COLUMN      16      ROWS     16 THRU     16     --------------------------------------------------
   ROW
    16)    5.0000D-01
COLUMN      17      ROWS     17 THRU     17     --------------------------------------------------
   ROW
    17)    1.0000D+00
COLUMN      18      ROWS     18 THRU     18     --------------------------------------------------
   ROW
    18)    1.0000D+00
COLUMN      19      ROWS     19 THRU     19     --------------------------------------------------
   ROW
    19)    5.0000D-01
COLUMN      20      ROWS     20 THRU     20     --------------------------------------------------
   ROW
    20)    1.0000D+00
COLUMN      21      ROWS     21 THRU     21     --------------------------------------------------
   ROW
    21)    1.0000D+00

THE NUMBER OF NON-ZERO TERMS IN THE DENSEST COLUMN =       1

THE DENSITY OF THIS MATRIX IS   4.76 PERCENT.
```

Listing 8-13 Output for Jet Transport Wing/Aileron by Strip Theory (Continued)

```
                                       FLUTTER  SUMMARY
POINT =    1     MACH NUMBER =  0.0000     DENSITY RATIO =  1.0000E+00     METHOD = PK

  KFREQ           1./KFREQ         VELOCITY           DAMPING          FREQUENCY            COMPLEX   EIGENVALUE
 0.1766        5.6623220E+00    4.0000000E+02    -2.4420439E-01     2.0561607E+00     -1.5774674E+00     1.2919239E+01
 0.1415        7.0673518E+00    5.0000000E+02    -3.2955328E-01     2.0592303E+00     -2.1319668E+00     1.2938526E+01
 0.1178        8.4884424E+00    6.0000000E+02    -4.3011853E-01     2.0573816E+00     -2.7800519E+00     1.2926910E+01
 0.1004        9.9567423E+00    7.0000000E+02    -5.5466795E-01     2.0463145E+00     -3.5657868E+00     1.2857374E+01
 0.0865        1.1554445E+01    8.0000000E+02    -7.1936250E-01     2.0152667E+00     -4.5543900E+00     1.2662294E+01
 0.0742        1.3476210E+01    9.0000000E+02    -9.5377046E-01     1.9438661E+00     -5.8245196E+00     1.2213672E+01
 0.0611        1.6379684E+01    1.0000000E+03    -1.3574114E+00     1.7769945E+00     -7.5778751E+00     1.1165186E+01
 0.0528        1.8946871E+01    1.0497999E+03    -1.7367283E+00     1.6127264E+00     -8.7991858E+00     1.0133060E+01
 0.0000        9.9999996E+24    1.0499000E+03    -1.9979893E-01     0.0000000E+00     -1.3295465E+01     0.0000000E+00
 0.0000        9.9999996E+24    1.1000000E+03    -1.0474118E-01     0.0000000E+00     -7.3025169E+00     0.0000000E+00
 0.0000        9.9999996E+24    1.2000000E+03    -5.2409641E-02     0.0000000E+00     -3.9861615E+00     0.0000000E+00
 0.0000        9.9999996E+24    1.3000000E+03    -2.3549685E-02     0.0000000E+00     -1.9403983E+00     0.0000000E+00
 0.0000        9.9999996E+24    1.4199000E+03    -1.6661106E-04     0.0000000E+00     -1.4994225E-02     0.0000000E+00
 0.0000        9.9999996E+24    1.5000000E+03     1.1860256E-02     0.0000000E+00      1.1275811E+00     0.0000000E+00
 0.0000        9.9999996E+24    1.6000000E+03     2.4461586E-02     0.0000000E+00      2.4806590E+00     0.0000000E+00
 0.0000        9.9999996E+24    1.7000000E+03     3.5293423E-02     0.0000000E+00      3.8028150E+00     0.0000000E+00
 0.0000        9.9999996E+24    1.8000000E+03     4.4955902E-02     0.0000000E+00      5.1288700E+00     0.0000000E+00
 0.0000        9.9999996E+24    1.9000000E+03     5.3828783E-02     0.0000000E+00      6.4823227E+00     0.0000000E+00
 0.0000        9.9999996E+24    2.0000000E+03     6.2168136E-02     0.0000000E+00      7.8806186E+00     0.0000000E+00
 0.0000        9.9999996E+24    2.1000000E+03     7.0166565E-02     0.0000000E+00      9.3392496E+00     0.0000000E+00
POINT =    2     MACH NUMBER =  0.0000     DENSITY RATIO =  1.0000E+00     METHOD = PK

 KFREQ           1./KFREQ         VELOCITY           DAMPING          FREQUENCY            COMPLEX   EIGENVALUE
 0.2987        3.3474324E+00    4.0000000E+02    -3.9937280E-02     3.4780819E+00     -4.3638334E-01     2.1853434E+01
 0.2360        4.2375751E+00    5.0000000E+02    -5.0273400E-02     3.4343474E+00     -5.4241586E-01     2.1578642E+01
 0.1934        5.1695476E+00    6.0000000E+02    -5.8159672E-02     3.3782387E+00     -6.1725152E-01     2.1226101E+01
 0.1625        6.1536241E+00    7.0000000E+02    -6.1284974E-02     3.3109965E+00     -6.3747424E-01     2.0803606E+01
 0.1390        7.1942186E+00    8.0000000E+02    -5.7188056E-02     3.2366669E+00     -5.8150470E-01     2.0336578E+01
 0.1207        8.2822332E+00    9.0000000E+02    -4.4563793E-02     3.1629088E+00     -4.4281128E-01     1.9873142E+01
 0.1064        9.3984213E+00    1.0000000E+03    -2.5869235E-02     3.0969679E+00     -2.5169244E-01     1.9458824E+01
 0.1004        9.9602737E+00    1.0497999E+03    -1.5862148E-02     3.0677991E+00     -1.5287583E-01     1.9275551E+01
 0.1004        9.9615774E+00    1.0499000E+03    -1.5506835E-02     3.0676894E+00     -1.4944606E-01     1.9274862E+01
 0.0950        1.0529980E+01    1.1000000E+03    -5.5110450E-03     3.0405822E+00     -5.2642994E-02     1.9104542E+01
 0.0857        1.1674541E+01    1.2000000E+03     1.2074869E-02     2.9918036E+00      1.1349204E-01     1.8798058E+01
 0.0779        1.2835329E+01    1.3000000E+03     2.4647040E-02     2.9480033E+00      2.2826675E-01     1.8522852E+01
 0.0702        1.4254667E+01    1.4199000E+03     2.8739441E-02     2.8992944E+00      2.6177040E-01     1.8216805E+01
 0.0657        1.5218550E+01    1.5000000E+03     2.6729194E-02     2.8688617E+00      2.4090476E-01     1.8025591E+01
 0.0608        1.6439577E+01    1.6000000E+03     1.5277724E-02     2.8328331E+00      1.3596575E-01     1.7799215E+01
 0.0566        1.7676716E+01    1.7000000E+03    -8.5209534E-03     2.7992325E+00     -7.4933678E-02     1.7588097E+01
 0.0528        1.8925205E+01    1.8000000E+03    -5.0853573E-02     2.7683661E+00     -4.4227752E-01     1.7394157E+01
 0.0495        2.0184956E+01    1.9000000E+03    -1.1562889E-01     2.7397909E+00     -9.9525338E-01     1.7214615E+01
 0.0465        2.1496552E+01    2.0000000E+03    -2.1412642E-01     2.7080259E+00     -1.8216838E+00     1.7015030E+01
 0.0434        2.3034266E+01    2.1000000E+03    -3.6526951E-01     2.6536067E+00     -3.0450881E+00     1.6673103E+01
POINT =    3     MACH NUMBER =  0.0000     DENSITY RATIO =  1.0000E+00     METHOD = PK

 KFREQ           1./KFREQ         VELOCITY           DAMPING          FREQUENCY            COMPLEX   EIGENVALUE
 0.6214        1.6091905E+00    4.0000000E+02    -4.9142484E-02     7.2350936E+00     -1.1169947E+00     4.5459435E+01
 0.4983        2.0068948E+00    5.0000000E+02    -6.5004468E-02     7.2516527E+00     -1.4809148E+00     4.5563480E+01
 0.4162        2.4028482E+00    6.0000000E+02    -8.2334675E-02     7.2680273E+00     -1.8799626E+00     4.5666363E+01
 0.3575        2.7971790E+00    7.0000000E+02    -1.0112985E-01     7.2839913E+00     -2.3141882E+00     4.5766670E+01
 0.3135        3.1901231E+00    8.0000000E+02    -1.2165799E-01     7.2991819E+00     -2.7897463E+00     4.5862114E+01
 0.2792        3.5823009E+00    9.0000000E+02    -1.4434153E-01     7.3126035E+00     -3.3159900E+00     4.5946445E+01
 0.2516        3.9747384E+00    1.0000000E+03    -1.6996393E-01     7.3228993E+00     -3.9101164E+00     4.6011135E+01
 0.2398        4.1707745E+00    1.0497999E+03    -1.8402000E-01     7.3262458E+00     -4.2354193E+00     4.6032162E+01
 0.2397        4.1711688E+00    1.0499000E+03    -1.8404870E-01     7.3262506E+00     -4.2360826E+00     4.6032192E+01
 0.2289        4.3693166E+00    1.1000000E+03    -1.9958718E-01     7.3277521E+00     -4.5946593E+00     4.6041626E+01
 0.2096        4.7704153E+00    1.2000000E+03    -2.3574747E-01     7.3217797E+00     -5.4226751E+00     4.6004101E+01
 0.1927        5.1888719E+00    1.3000000E+03    -2.8228080E-01     7.2922583E+00     -6.4668570E+00     4.5818611E+01
 0.1735        5.7622743E+00    1.4199000E+03    -3.6187363E-01     7.1722507E+00     -8.1538420E+00     4.5064583E+01
 0.1593        6.2764869E+00    1.5000000E+03    -4.3319976E-01     6.9561071E+00     -9.4668255E+00     4.3706512E+01
 0.1390        7.1964941E+00    1.6000000E+03    -4.9804926E-01     6.4712863E+00     -1.0125415E+01     4.0660294E+01
 0.1214        8.2375851E+00    1.7000000E+03    -4.7451165E-01     6.0067649E+00     -8.9544191E+00     3.7741619E+01
 0.1088        9.1920557E+00    1.8000000E+03    -4.0002409E-01     5.6996932E+00     -7.1628771E+00     3.5812229E+01
 0.0989        1.0114189E+01    1.9000000E+03    -3.0531022E-01     5.4678192E+00     -5.2445159E+00     3.4355324E+01
 0.0903        1.1070879E+01    2.0000000E+03    -1.9264352E-01     5.2582293E+00     -3.1823196E+00     3.3038429E+01
 0.0826        1.2109256E+01    2.1000000E+03    -5.5049565E-02     5.0476995E+00     -8.7296593E-01     3.1715633E+01
```

Listing 8-13 Output for Jet Transport Wing/Aileron by Strip Theory (Continued)

```
POINT =    4     MACH NUMBER =  0.0000     DENSITY RATIO =  1.0000E+00     METHOD = PK

KFREQ          1./KFREQ        VELOCITY          DAMPING          FREQUENCY          COMPLEX   EIGENVALUE
 0.9954      1.0046399E+00   4.0000000E+02   -2.5909605E-02   1.1588873E+01   -9.4330442E-01   7.2815041E+01
 0.7976      1.2537988E+00   5.0000000E+02   -3.3145003E-02   1.1607368E+01   -1.2086531E+00   7.2931244E+01
 0.6658      1.5019433E+00   6.0000000E+02   -4.1014399E-02   1.1627580E+01   -1.4982200E+00   7.3058243E+01
 0.5718      1.7488163E+00   7.0000000E+02   -4.9539886E-02   1.1650524E+01   -1.8132195E+00   7.3202408E+01
 0.5015      1.9939029E+00   8.0000000E+02   -5.8691785E-02   1.1678246E+01   -2.1533015E+00   7.3376587E+01
 0.4471      2.2363906E+00   9.0000000E+02   -6.8367414E-02   1.1713494E+01   -2.5158546E+00   7.3598061E+01
 0.4041      2.4745743E+00   1.0000000E+03   -7.8291900E-02   1.1762270E+01   -2.8930628E+00   7.3904526E+01
 0.3860      2.5903931E+00   1.0497999E+03   -8.2976714E-02   1.1795939E+01   -3.0749540E+00   7.4116074E+01
 0.3860      2.5906236E+00   1.0499000E+03   -8.2984276E-02   1.1796012E+01   -3.0752535E+00   7.4116531E+01
 0.3698      2.7040808E+00   1.1000000E+03   -8.6826794E-02   1.1840352E+01   -3.2297451E+00   7.4395126E+01
 0.3424      2.9201806E+00   1.2000000E+03   -8.3763912E-02   1.1960880E+01   -3.1475306E+00   7.5152428E+01
 0.3110      3.2153144E+00   1.3000000E+03   -2.8281605E-01   1.1768241E+01   -1.0455997E+01   7.3942039E+01
 0.2686      3.7228286E+00   1.4199000E+03   -3.1635937E-01   1.1101364E+01   -1.1033339E+01   6.9751930E+01
 0.2436      4.1048670E+00   1.5000000E+03   -3.0202147E-01   1.0636134E+01   -1.0091866E+01   6.6828804E+01
 0.2186      4.5751591E+00   1.6000000E+03   -2.2783104E-01   1.0179007E+01   -7.2856479E+00   6.3956589E+01
 0.2001      4.9973831E+00   1.7000000E+03   -1.3295659E-01   9.9014301E+00   -4.1357822E+00   6.2212521E+01
 0.1846      5.4175787E+00   1.8000000E+03   -5.5197932E-02   9.6707220E+00   -1.6769943E+00   6.0762939E+01
 0.1707      5.8579936E+00   1.9000000E+03    1.5998115E-03   9.4405289E+00    4.7447685E-02   5.9316597E+01
 0.1581      6.3244147E+00   2.0000000E+03    3.9703224E-02   9.2045231E+00    1.1480926E+00   5.7833725E+01
 0.1467      6.8187490E+00   2.1000000E+03    6.1259042E-02   8.9640903E+00    1.7251478E+00   5.6323044E+01
```

Subsonic Flutter Analysis of the 15-Degree Sweptback Wing by the KE-Method (Example HA145E)

The subsonic flutter characteristics of several flat-plate flutter models were reported by Tuovila and McCarty (1955) [Reference 60] and investigated further by Yates and Bennett (1963) [Reference 64]. The untapered wing with 15 deg of sweepback was analyzed by Rodden, Harder, and Bellinger (1979) [Reference 50] with its structure idealized as a "stick" model and with aerodynamic forces calculated by the Doublet-Lattice method. Both the calculated flutter speed and frequency were higher than test results in the earlier three-mode solution. The purpose of this example is to reconsider the analysis of Rodden, Harder, and Bellinger (1979) [Reference 50] with a structural plate model and to demonstrate the KE-method of flutter analysis.

Representation of the model by CQUAD4 elements is more realistic. Such a structural model was developed for the static aeroelastic analysis in Example HA144C (p. 258). For the static analysis, nominal values of moduli of elasticity and density of aluminum were used and a rigidly clamped support was assumed. However, modifications are appropriate in view of the experimental data. The nominal density of $0.100\ \mathrm{lb/in}^3$ results in a model weight of 0.041041 lb, whereas the measured weight was 0.040 lb. Therefore, an adjusted density of $0.097464\ \mathrm{lb/in}^3$ is used. The other experimental data are the first three vibration frequencies and node lines. The structural root model of Example HA144C was modified to investigate the effect of constraints on the second (torsion) node line. The RBAR was removed and Grid Points 9, 17, and 25 were given single-point constraints, and variations in root constraints were investigated. A free GRID 17 resulted in an improved correlation with the node lines of Yates and Bennett (1963) [Reference 64], therefore GRIDs 9 and 25 are assumed to be fully constrained and GRID 17 is assumed unconstrained in the flutter analysis. With the root so constrained and the adjusted density, the nominal values of moduli, $E = 10.3 \times 10^6\ \mathrm{psi}$ and $G = 3.9 \times 10^6\ \mathrm{psi}$, resulted in a second vibration frequency of 221.697 Hz as compared to the experimental value of 210 Hz. The moduli were then scaled by the square of the frequency ratio to be $E = 9.2418 \times 10^6\ \mathrm{psi}$ and $G = 3.4993 \times 10^6\ \mathrm{psi}$. It is not likely that the material moduli were so low; it is more likely that there was additional flexibility in the model support system. The adjusted moduli result in the first three natural frequencies of 34.3, 210.0, and 260.4 Hz that may be compared to the experimental values of 36.0, 210.0, and 242.0 Hz. The variation in experimental frequencies is indicated by the measured frequencies on the similar aluminum model for the Mach 1.3 test that were 36.0, 210.0, and 254.0 Hz.

Bulk Data Entries

The Bulk Data Section builds on that of Example HA144C (p. 258) for the basic structural and aerodynamic data. The parameter PARAM,GRDPNT,17 has been added to obtain the weight data that permitted adjusting the density. The KE-method of flutter analysis is being demonstrated in this example. Since the KE-method permits inclusion of damping only as a complex frequency dependent factor in the structural stiffness, structural damping is included by means of the parameter PARAM,KDAMP,-1 and the TABDMP1 table. No damping data were reported by Tuovila and McCarty (1955) [Reference 60] so a value of $g = 0.01$ is assumed up to a frequency of 1000.0 Hz.

The aerodynamic data begin with the AERO entry that uses the basic coordinate system for the aerodynamic coordinate system, a reference chord of 2.0706 in., sea-level reference density, $\mathrm{SYMXZ} = 1$ for a complete wind tunnel wall reflection, and $\mathrm{SYMXY} = 0$ to neglect wind tunnel floor or ceiling interference. The CAERO1, PAERO1, SPLlNE1 and SET1 entries provide the aerodynamic geometry and surface spline data and are the same as in Example HA144C (p. 258). The MKAERO1 entry provides the data required to interpolate the aerodynamic matrices in the flutter solution. The Mach number, $m = 0.45$, and reduced frequencies, $k = 0.001$, 0.10, 0.12, 0.14, 0.16 and 0.20, are specified to encompass the experimental value of $k = 0.1314$.

The Modified Givens method is selected for vibration analysis on the EIGR entry to obtain four modes that have their largest components normalized to unity. The parameter PARAM,LMODES,4 specifies that all four vibration modes be included in the formulation of the flutter problem.

The FLUTTER entry specifies the KE-method of flutter analysis. Note that no EIGC entry is required since the Upper Hessenberg method is built into the KE-method for complex eigenvalues. The FLUTTER entry also identifies the three FLFACT entries that list the densities, Mach numbers and reduced frequencies, and specifies linear interpolation for the aerodynamic generalized force influence coefficients. The data item NVALUE is left blank so the KE-method computes the default LMODES complex eigenvalues. FLFACT 1 gives the density ratio for the wind tunnel test, FLFACT 2 gives the test Mach number, and FLFACT 3 gives the series of reduced frequencies for the flutter analysis. The output flutter velocities in the summary are converted from the analysis units of in/s to ft/s by means of the parameter PARAM,VREF,12.0. The Bulk Data Section ends with the ENDDATA entry.

Case Control Commands

The first three entries in the Case Control Section are titles. ECHO = BOTH requests the input data be printed in unsorted and sorted formats. SPC = 1 selects the constraints on the wing root deflections and on the plate element in-plane rotations. SDAMP = 2000 invokes the tabular Bulk Data for structural damping. METHOD = 10 selects the eigenvalue method for the vibration analysis, and FMETHOD = 30 selects the method of flutter analysis. SVEC = ALL requests printed output of the displacements of the grid point degrees of freedom in the analysis set (a-set), which in this case are the transverse deflections in the vibration modes.

The OUTPUT(PLOT) entry identifies the plot packet for the structure plotter. CSCALE 2.0 specifies spacing of characters in the plot title. The set of elements to be plotted are the QUAD4s. The FIND entry determines a scale and origin for the plots. The PLOT entry requests plots of the vibration modes with undeformed underlays. The OUTPUT(XYOUT) entry identifies the plot packet for xy-plots. CURVELINESYMBOL = 6 requests points on the first curve to be identified by circle symbols. XYPLOT VG/1 (G,F) 2(G,F) 3(G,F) requests two types of xy-plots: plots of velocity (x-axis) versus damping (y-axis) on the upper half of each frame and velocity versus frequency (y-axis) on the lower half of each frame. Three curves are requested and represent the first three modes. YTTITLE and YBTITLE request titles for the top and bottom plots. Similarly, XTGRID, etc. request that reference lines be drawn on the plots at equal increments. BEGIN BULK completes the Case Control Section.

The Executive Control Section begins with the problem identification, ID MSC, HA145E. TIME 5 limits the CPU time to 5.0 minutes, and SOL 145 requests the Structured Aerodynamic Flutter DMAP sequence. The CEND entry completes the Executive Control Section.

Output

The input data for this example are shown in Listing 8-14 and Listing 8-15 and limited output data follow in Listing 8-16. The output data are discussed below.

The output consists of the weight and inertial data (which were used to monitor the model weight and adjust the structural density), the vibration frequencies and the four (LMODES = 4) vibration modal deflections for the a-set grid points, and the Flutter Summaries. The sorting algorithm in the KE-method is shown in (2-170) and (2-171) and the “Points” in the Summary Tables are not necessarily in the order of ascending modes. In this example, Point 1 is the third mode, Point 2 is the second (critical) mode, Point 3 is the fourth mode, and Point 4 is the first mode. This is the order in which the complex eigenvalues for the first value of reduced frequency were output from the eigenvalue subroutine.

The flutter data from Point 2 are plotted in Figure 8-9 along with the experimental data. The present four mode solution gives a flutter speed of $V_f = 483\ \text{ft/sec}$ and flutter frequency of $f_f = 113.0\ \text{Hz}$. The test results were $V_f = 495\ \text{ft/sec}$ and $f_f = 120\ \text{Hz}$. The earlier analysis of Rodden, Harder, and Bellinger (1979, Fig. 14 [Reference 50]), using the structural stick model, and three vibration modes obtained $V_f = 509\ \text{ft/sec}$ and $f_f = 134\ \text{Hz}$ without any adjustment of that model to agree with the measured vibration frequencies or including any structural damping.

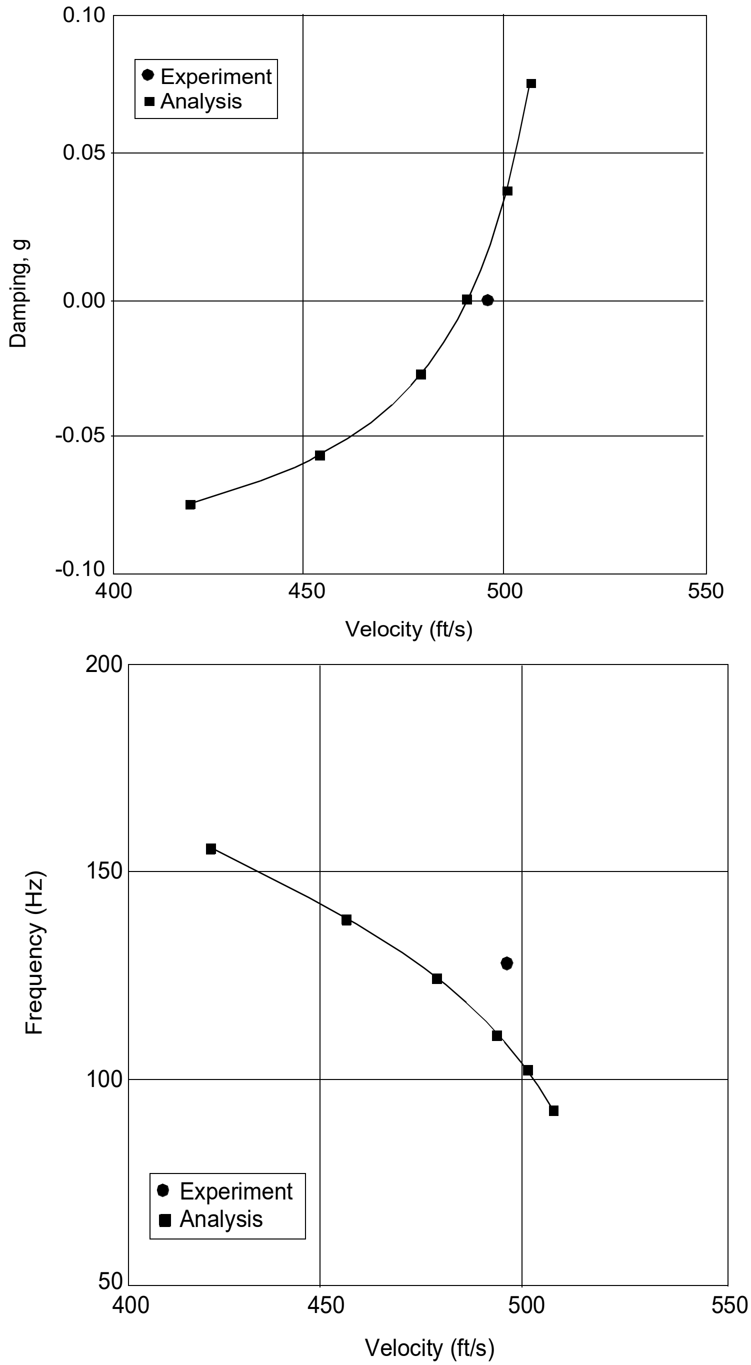

Figure 8-9 Critical Subsonic Flutter V-g and V-f Curves for 15-Degree Sweptback Wing

Listing 8-14 Input Data for the 15-Degree Sweptback Wing by KE-Method

```
    N A S T R A N   E X E C U T I V E   C O N T R O L   D E C K   E C H O

ID MSC, HA145E
$$$$$$$$ HANDBOOK FOR AEROELASTIC ANALYSIS EXAMPLE HA145E       $$$$$$$$
$                                                                      $
$       MODEL DESCRIPTION       MODEL A OF NASA TN D-1824              $
$                               HALF SPAN 15 DEGREE SWEPT WING         $
$                               28 QUAD4 PANEL MODEL                   $
$                                                                      $
$       SOLUTION                KE FLUTTER ANALYSIS METHOD             $
$                               USING DOUBLET LATTICE METHOD           $
$                               AERODYNAMICS AT MACH NO. 0.45          $
$                                                                      $
$       OUTPUT                  PLOTS OF VIBRATION MODES AND X-Y       $
$                               PLOTS OF V-G FLUTTER DATA              $
$                                                                      $
$$$$$$$$                                                        $$$$$$$$
TIME 5 $
SOL 145  $ FLUTTER ANALYSIS
CEND

EXAMPLE HA145E: HALF SPAN 15-DEG SWEPT UNTAPERED WING                                          PAGE 2
      KE-METHOD FLUTTER ANALYSIS, DOUBLET-LATTICE AERO

     0.041 IN AL PLATE W/BEVELLED LEADING AND TRAILING EDGES

                                   C A S E   C O N T R O L   D E C K   E C H O
         CARD
         COUNT
          1      TITLE = EXAMPLE HA145E: HALF SPAN 15-DEG SWEPT UNTAPERED WING
          2      SUBT  = KE-METHOD FLUTTER ANALYSIS, DOUBLET-LATTICE AERO
          3      LABEL = 0.041 IN AL PLATE W/BEVELLED LEADING AND TRAILING EDGES
          4        ECHO    = BOTH
          5        SPC     = 1    $ WING ROOT DEFLECTIONS AND PLATE IN-PLANE ROTATIONS FIXED
          6        SDAMP   = 2000
          7        METHOD  = 10   $ MODIFIED GIVENS METHOD OF REAL EIGENVALUE EXTRACTION
          8        FMETHOD = 30   $ KE-FLUTTER METHOD
          9        SVEC    = ALL $ PRINT VIBRATION MODES
         10      OUTPUT(PLOT)
         11        CSCALE 2.0
         12        PLOTTER NASTRAN
         13        SET 1  = QUAD4
         14        PTITLE = STRUCTURAL ELEMENTS
         15        FIND SCALE, ORIGIN 1, SET 1
         16        PLOT MODAL 0 ORIGIN 1, SET 1
         17      OUTPUT (XYOUT)
         18        CSCALE 2.0
         19        PLOTTER NASTRAN
         20        CURVELINESYMBOL = 6
         21        YTTITLE = DAMPING  G
         22        YBTITLE = FREQUENCY  F  HZ
         23        XTITLE  = VELOCITY  V (FT/S)
         24        XTGRID LINES = YES
         25        XBGRID LINES = YES
         26        YTGRID LINES = YES
         27        YBGRID LINES = YES
         28        UPPER TICS  = -1
         29        TRIGHT TICS = -1
         30        BRIGHT TICS = -1
         31        XYPLOT VG / 1(G,F) 2(G,F) 3(G,F)
         32      BEGIN BULK
```

Listing 8-14 Input Data for the 15-Degree Sweptback Wing by KE-Method (Continued)

```
EXAMPLE HA145E: HALF SPAN 15-DEG SWEPT UNTAPERED WING                                                         PAGE     3
 KE-METHOD FLUTTER ANALYSIS, DOUBLET-LATTICE AERO

 0.041 IN AL PLATE W/BEVELLED LEADING AND TRAILING EDGES

                                              I N P U T   B U L K   D A T A   D E C K   E C H O
                                        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                                        $*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
                                        $                                                                        $
                                        $        THE ANNOTATIONS IN THIS INPUT DECK ARE INTENDED TO              $
                                        $        EXPLAIN THE DATA ON THE CARD IMAGES FOR THIS                    $
                                        $        EXAMPLE WITHOUT REFERENCE TO THE VARIOUS MANUALS WHERE          $
                                        $        MORE GENERAL DESCRIPTIONS WILL BE FOUND.                        $
                                        $                                                                        $
                                        $*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
                                        $                                                                        $
                                        INCLUDE PLATE_STRUCT.DAT
                                        $
                                        $                 * * MASS AND INERTIA PROPERTIES * *                    $
                                        $                                                                        $
                                        $        THE MAT1 ENTRY DEFINES THE MATERIAL PROPERTIES FOR LINEAR,      $
                                        $        TEMPERATURE-INDEPENDENT, ISOTROPIC MATERIALS.  IT LISTS         $
                                        $        YOUNGS MODULUS, THE SHEAR MODULUS, POISSONS RATIO, MASS         $
                                        $        DENSITY, THERMAL EXPANSION COEFFICIENT AND STRUCTURAL           $
                                        $        ELEMENT DAMPING.                                                $
                                        $                                                                        $
                                        $       MID     E       G       NU      RHO     A       TREF    GE
                                        MAT1    1       9.2418+63.4993+6        0.097464
                                        $
                                        $        PARAM GRDPNT CAUSES THE INERTIAL MATRIX TO BE GENERATED WITH    $
                                        $        RESPECT TO COORDINATES THROUGH THE GRID POINT SPECIFIED.        $
                                        $
                                        PARAM    GRDPNT  17
                                        $                                                                        $
                                        $                    * * STRUCTURAL CONSTRAINTS * *                      $
                                        $                                                                        $
                                        $        THE SPC1 ENTRY DEFINES SETS OF SINGLE-POINT CONSTRAINTS.        $
                                        $        IT LISTS THE DOF COMPONENTS TO BE CONSTRAINED AND THE GRID      $
                                        $        POINT NO.                                                       $
                                        $                                                                        $
                                        $       SID     C       G1      G2      ETC                              $
                                        SPC1    1       12345   9
                                        SPC1    1       12345   25
                                        SPC1    1       6       1       THRU    40
                                        $                                                                        $
                                        $        THE ASET1 ENTRY DEFINES DOFS THAT THE USER DESIRES TO BE        $
                                        $        IN THE ANALYSIS SET. IT LISTS THE DOF COMPONENT NUMBERS         $
                                        $        AND THE GRID ID NOS.                                            $
                                        $                                                                        $
                                        $       V       ID1     THRU    ID2
                                        ASET1   3        1      THRU     8
                                        ASET1   3       10      THRU    16
                                        ASET1   3       18      THRU    24
                                        ASET1   3       26      THRU    40
                                        $                                                                        $
                                        $                      *  STRUCTURAL DAMPING *                           $
                                        $                                                                        $
                                        $        THE PARAMETER KDAMP DETERMINES THE MANNER OF INCLUDING          $
                                        $        STRUCTURAL DAMPING IN THE EQUATIONS OF MOTION (SEE THE          $
                                        $        HANDBOOK FOR DYNAMIC ANALYSIS, SECTION 3.2.2).  IF SET TO       $
                                        $        -1, MODAL STRUCTURAL DAMPING IS INCLUDED AS THE IMAGINARY       $
                                        $        PART OF A COMPLEX STIFFNESS MATRIX.                             $
                                        $                                                                        $
                                        $       N       V1      V2                                               $
                                        PARAM   KDAMP   -1
                                        $                                                                        $
                                        $        THE TABDMP1 ENTRY AND TABLE DEFINE MODAL DAMPING AS A           $
                                        $        TABULAR FUNCTION OF FREQUENCY.  THE DAMPING VALUES ARE          $
                                        $        LINEAR BETWEEN THE FREQUENCY AND DAMPING PAIRS AND ARE          $
                                        $        EXTRAPOLATED OUTSIDE THE TABULATED FREQUENCY RANGE.             $
                                        $                                                                        $
                                        $       ID                                                               +TDP
                                        TABDMP1 2000                                                             +T2000
                                        $       F1      G1      F2      G2      ETC             ENDT
                                        +T2000  0.0     0.01    1000.0  0.01    ENDT
                                        $                                                                        $
```

Listing 8-14 Input Data for the 15-Degree Sweptback Wing by KE-Method (Continued)

```
$                    * * * AERODYNAMIC DATA * * *                      $
$                                                                      $
$                        (LB-IN-SEC SYSTEM)                            $
$                                                                      $
$                       * * ELEMENT GEOMETRY * *                       $
$                                                                      $
$        THE AERO ENTRY SPECIFIES THE AERO COORDINATE SYSTEM, THE      $
$        VELOCITY (USED FOR DATA RECOVERY), THE REFERENCE CHORD        $
$        AND FLUID DENSITY, PLUS SYMMETRY KEYS.  SYMXZ=0 INDICATES     $
$        THAT THE MODEL IS MOUNTED AS AN ISOLATED WING; SYMXY = 0      $
$        ASSUMES THAT THE MODEL IS MOUNTED FAR ENOUGH FROM THE         $
$        FLOOR SO THAT REFLECTION EFFECTS ARE NEGLIGIBLE.              $
$                                                                      $
$       ACSID   VELOCITY REFC   RHOREF  SYMXZ   SYMXY
AERO    0               2.0706  1.1092-7 1
$                                                                      $
$        THE CAERO1 ENTRY IS USED FOR DOUBLET-LATTICE AERODYNAMICS.    $
$        LISTED ARE ITS PAERO ENTRY ID AND THE COORDINATE SYSTEM       $
$        FOR LOCATING THE INBOARD AND OUTBOARD LEADING EDGE POINTS     $
$        (1 AND 4).  NSPAN AND NCHORD, OR LSPAN AND LCHORD, ARE        $
$        USED TO PARTITION THE WING INTO AERODYNAMIC PANELS.           $
$        THE FORMER FOR UNIFORMLY SPACED PANELS AND THE LATTER         $
$        FOR NON-UNIFORM SPACING.  IGID IS THE ID OF ITS ASSOCIATED    $
$        INTERFERENCE GROUP.  THE CONTINUATION ENTRY DEFINES POINTS    $
$        1 AND 4, THE ROOT CHORD AND TIP CHORD.  THE BOXES FORMED      $
$        BY THE GRID LINES WILL BE NUMBERED BEGINNING WITH EID         $
$        SO CHOOSE A NUMBER THAT IS UNIQUE, AND IS GREATER THAN ALL    $
$        STRUCTURAL GRID, SCALAR AND EXTRA POINT IDS.                  $
$                                                                      $
$       EID     PID     CP      NSPAN   NCHORD  LSPAN   LCHORD  IGID
CAERO1  101     1       0       6       4                       1       +CA101
$      ( FWD LEFT POINT  )   ROOTCHORD ( FWD RIGHT POINT  )  TIP CHORD
$       X1      Y1      Z1      X12     X4       Y4     Z4      X14
+CA101  .0      .0      .0      2.07055 1.48044 5.52510 0.0     2.07055
$                                                                      $
$        THE PAERO1 ENTRY IS REQUIRED EVEN THOUGH IT IS NON-FUNCTIONAL $
$        (BECAUSE THERE ARE NO ASSOCIATED BODIES IN THIS EXAMPLE).     $
$                                                                      $
$       PID     B1      B2      B3      B4      B5      B6
PAERO1  1
$                                                                      $
$              * * SPLINE FIT ON THE LIFTING SURFACES * *              $
$                                                                      $
$                  * SURFACE SPLINE FIT ON THE WING *                  $
$
$        THE SPLINE1 ENTRY DEFINES A SURFACE SPLINE FOR INTERPO-       $
$        LATING OUT-OF-PLANE DISPLACEMENTS FROM THE STRUCTURAL         $
$        GRID POINTS ON THE SETG ENTRY TO THE SUB-REGION DEFINED       $
$        BY AERODYNAMIC BOXES 101 THRU 124 OF THE REGION ON THE        $
$        CAERO1 ENTRY.  DZ=0 SPECIFIES THAT NO SMOOTHING OF THE        $
$        SPLINE IS TO BE IMPOSED.                                      $
$                                                                      $
$       EID     CAERO   BOX1    BOX2    SETG    DZ                     $
SPLINE1 100     101     101     124     100     .0
$                                                                      $
$        THE SET1 ENTRY DEFINES THE SET OF POINTS TO BE USED BY        $
$        THE SURFACE SPLINE FOR INTERPOLATION.                         $
$                                                                      $
$       SID     G1      G2      G3      G4      ETC
SET1    100     2       4       6       8       9       11      13      +S1
+S1     15      18      20      22      24      25      27      29      +S2
+S2     31      34      36      38      40
$                                                                      $
$                      * * AERODYNAMIC DATABASE * *                    $
$                                                                      $
$        ALL COMBINATIONS OF MACH NUMBER AND REDUCED FREQUENCY LISTED  $
$        ON THE MKAERO1 ENTRY AND ITS CONTINUATION ENTRY WILL BE USED  $
$        TO GENERATE GENERALIZED AERO FORCE MATRICES.                  $
$                                                                      $
$        M1     M2      M3      ETC
MKAERO1 0.45                                                            +MK
$        K1     K2      K3      ETC
+MK     .001    0.10    0.12    0.14    0.16    0.20
$                                                                      $
```

Main Index

Listing 8-14 Input Data for the 15-Degree Sweptback Wing by KE-Method (Continued)

```
$                      * * VIBRATION ANALYSIS * *                         $
$                                                                         $
$        THE EIGR ENTRY SPECIFIES THE METHOD OF EXTRACTING THE EIGEN-     $
$        SOLUTIONS OF THE STRUCTURE; IN THIS CASE THE MODIFIED            $
$        GIVENS METHOD.  SIX MODES ARE DESIRED, NORMALIZED ON THE         $
$        MAXIMUM DISPLACEMENTS.                                           $
$                                                                         $
$       SID     METHOD  F1      F2              NO                        $
EIGR    10      MGIV                            4                         +ER
$       NORM                                                              $
+ER     MAX
$                                                                         $
$        THE PARAM,OPPHIPA,1 PROVIDES THE VIBRATION MODES FOR THE         $
$        MODAL PLOT REQUESTS.                                             $
$                                                                         $
PARAM   OPPHIPA 1
$                                                                         $
$                        * * FLUTTER ANALYSIS * *                         $
$                                                                         $
$        THE PARAM,LMODES,N ENTRY SPECIFIES THAT N VIBRATION MODES        $
$        ARE TO BE USED IN THE FLUTTER ANALYSIS.  IF A RESTART IS         $
$        CONTEMPLATED TO DELETE MODES FROM THE ANALYSIS LMODES            $
$        SHOULD BE LARGE ENOUGH TO ACCOMMODATE THE DELETION.              $
$                                                                         $
PARAM   LMODES  4
$                                                                         $
$        THE FLUTTER ENTRY DEFINES THE METHOD OF SOLUTION, IDENTIFIES     $
$        THE FLFACT ENTRIES THAT FOLL0W, SPECIFIES THE INTERPOLATION      $
$        METHOD, THE NUMBER OF ROOTS DESIRED IN THE OUTPUT AND THE        $
$        CRITERION FOR CONVERGENCE.                                       $
$                                                                         $
$       SID     METHOD  DENS    MACH    VEL     IMETH   NVALUE  EPS       $
FLUTTER 30      KE      1       2       3       L
$                                                                         $
$        FLFACT ENTRIES ARE USED TO SPECIFY DENSITY RATIOS, MACH NOS.     $
$        AND REDUCED FREQUENCIES/VELOCITIES FOR FLUTTER ANALYSES.         $
$                                                                         $
$       SID     F1      F2      F3      F4      F5      F6      F7        $
FLFACT  1       0.967                                                     DENSITY
FLFACT  2       .45                                                       MACH NO
FLFACT  3       .20000  .16667  .14286  .12500  .11111  .10000            RFREQ
$                                                                         $
$        THE PARAMETER VREF IS USED TO DIVIDE THE ANALYSIS UNITS          $
$        OF VELOCITY TO THOSE DESIRED IN THE FLUTTER SUMMARY, IN          $
$        THIS CASE FROM IN/S TO FT/S.                                     $
$                                                                         $
$       N       V1      V2
PARAM   VREF    12.0
$
ENDDATA
INPUT BULK DATA CARD COUNT =     321
```

Listing 8-15 Sorted Bulk Data Entries for the 15-Degree Sweptback Wing by KE-Method

```
EXAMPLE HA145E: HALF SPAN 15-DEG SWEPT UNTAPERED WING                                                PAGE    10
  KE-METHOD FLUTTER ANALYSIS, DOUBLET-LATTICE AERO

 0.041 IN AL PLATE W/BEVELLED LEADING AND TRAILING EDGES

                                             S O R T E D   B U L K   D A T A   E C H O
               CARD
               COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                  1-        AERO    0               2.0706  1.1092-71
                  2-        ASET1   3       1       THRU    8
                  3-        ASET1   3       10      THRU    16
                  4-        ASET1   3       18      THRU    24
                  5-        ASET1   3       26      THRU    40
                  6-        CAERO1  101     1       0       6       4                       1       +CA101
                  7-        +CA101  .0      .0      .0      2.07055 1.48044 5.52510 0.0     2.07055
                  8-        CQUAD4  1       1       1       2       10      9                       +M00000
                  9-        +M00000                 0.0     0.0     .041    .041
                 10-        CQUAD4  2       1       2       3       11      10                      +M00001
                 11-        +M00001                 0.0     0.0     .041    .041
                 12-        CQUAD4  3       1       3       4       12      11                      +M00002
                 13-        +M00002                 0.0     0.0     .041    .041
                 14-        CQUAD4  4       1       4       5       13      12                      +M00003
                 15-        +M00003                 0.0     0.0     .041    .041
                 16-        CQUAD4  5       1       5       6       14      13                      +M00004
                 17-        +M00004                 0.0     0.0     .041    .041
                 18-        CQUAD4  6       1       6       7       15      14                      +M00005
                 19-        +M00005                 0.0     0.0     .041    .041
                 20-        CQUAD4  7       1       7       8       16      15                      +M00006
                 21-        +M00006                 0.0     0.0     .041    .041
                 22-        CQUAD4  8       1       9       10      18      17
                 23-        CQUAD4  9       1       10      11      19      18
                 24-        CQUAD4  10      1       11      12      20      19
                 25-        CQUAD4  11      1       12      13      21      20
                 26-        CQUAD4  12      1       13      14      22      21
                 27-        CQUAD4  13      1       14      15      23      22
                 28-        CQUAD4  14      1       15      16      24      23
                 29-        CQUAD4  15      1       17      18      26      25
                 30-        CQUAD4  16      1       18      19      27      26
                 31-        CQUAD4  17      1       19      20      28      27
                 32-        CQUAD4  18      1       20      21      29      28
                 33-        CQUAD4  19      1       21      22      30      29
                 34-        CQUAD4  20      1       22      23      31      30
                 35-        CQUAD4  21      1       23      24      32      31
                 36-        CQUAD4  22      1       25      26      34      33                      +M00007
                 37-        +M00007                 .041    .041    0.0     0.0
                 38-        CQUAD4  23      1       26      27      35      34                      +M00008
                 39-        +M00008                 .041    .041    0.0     0.0
                 40-        CQUAD4  24      1       27      28      36      35                      +M00009
                 41-        +M00009                 .041    .041    0.0     0.0
                 42-        CQUAD4  25      1       28      29      37      36                      +M00010
                 43-        +M00010                 .041    .041    0.0     0.0
                 44-        CQUAD4  26      1       29      30      38      37                      +M00011
                 45-        +M00011                 .041    .041    0.0     0.0
                 46-        CQUAD4  27      1       30      31      39      38                      +M00012
                 47-        +M00012                 .041    .041    0.0     0.0
                 48-        CQUAD4  28      1       31      32      40      39                      +M00013
                 49-        +M00013                 .041    .041    0.0     0.0
                 50-        EIGR    10      MGIV                            4                       +ER
                 51-        +ER     MAX
                 52-        FLFACT  1       0.967                                                   DENSITY
                 53-        FLFACT  2       .45                                                     MACH NO
                 54-        FLFACT  3       .20000  .16667  .14286  .12500  .11111  .10000          RFREQ
                 55-        FLUTTER 30      KE      1       2       3       L
                 56-        GRID    1               0.0     0.0     0.0
                 57-        GRID    2               .211491 .7893   0.0
                 58-        GRID    3               .422983 1.5786  0.0
                 59-        GRID    4               .634474 2.3679  0.0
                 60-        GRID    5               .845966 3.1572  0.0
                 61-        GRID    6               1.05746 3.9465  0.0
                 62-        GRID    7               1.26895 4.7358  0.0
                 63-        GRID    8               1.48044 5.5251  0.0
                 64-        GRID    9               .258819 0.0     0.0
                 65-        GRID    10              .47031  .7893   0.0
                 66-        GRID    11              .681802 1.5786  0.0
                 67-        GRID    12              .893293 2.3679  0.0
```

Listing 8-15 Sorted Bulk Data Entries for the 15-Degree Sweptback Wing by KE-Method (Continued)

```
  68-        GRID    13              1.10478 3.1572  0.0
  69-        GRID    14              1.31628 3.9465  0.0

  70-        GRID    15              1.52777 4.7358  0.0
  71-        GRID    16              1.73926 5.5251  0.0
  72-        GRID    17              1.03528 0.0     0.0
  73-        GRID    18              1.24677 .7893   0.0
  74-        GRID    19              1.45826 1.5786  0.0
  75-        GRID    20              1.66975 2.3679  0.0
  76-        GRID    21              1.88124 3.1572  0.0
  77-        GRID    22              2.09273 3.9465  0.0
  78-        GRID    23              2.30422 4.7358  0.0
  79-        GRID    24              2.51572 5.5251  0.0
  80-        GRID    25              1.81173 0.0     0.0
  81-        GRID    26              2.02322 .7893   0.0
  82-        GRID    27              2.23471 1.5786  0.0
  83-        GRID    28              2.44621 2.3679  0.0
  84-        GRID    29              2.6577  3.1572  0.0
  85-        GRID    30              2.86919 3.9465  0.0
  86-        GRID    31              3.08068 4.7358  0.0
  87-        GRID    32              3.29217 5.5251  0.0
  88-        GRID    33              2.07055 0.0     0.0
  89-        GRID    34              2.28204 .7893   0.0
  90-        GRID    35              2.49353 1.5786  0.0
  91-        GRID    36              2.70502 2.3679  0.0
  92-        GRID    37              2.91652 3.1572  0.0
  93-        GRID    38              3.12801 3.9465  0.0
  94-        GRID    39              3.3395  4.7358  0.0
  95-        GRID    40              3.55099 5.5251  0.0
  96-        MAT1    1       9.2418+63.4993+6        0.097464
  97-        MKAERO1 0.45                                                    +MK
  98-        +MK     .001    0.10    0.12    0.14    0.16    0.20
  99-        PAERO1  1
 100-        PARAM   COUPMASS1
 101-        PARAM   GRDPNT  17
 102-        PARAM   KDAMP   -1
 103-        PARAM   LMODES  4
 104-        PARAM   OPPHIPA 1
 105-        PARAM   VREF    12.0
 106-        PARAM   WTMASS  .0025901
 107-        PSHELL  1       1       .041    1               1
 108-        SET1    100     2       4       6       8       9       11      13      +S1
 109-        +S1     15      18      20      22      24      25      27      29      +S2
 110-        +S2     31      34      36      38      40
 111-        SPC1    1       6       1       THRU    40
 112-        SPC1    1       12345   9
 113-        SPC1    1       12345   25
 114-        SPLINE1 100     101     101     124     100     .0
 115-        TABDMP1 2000                                                    +T2000
 116-        +T2000  0.0     0.01    1000.0  0.01    ENDT
             ENDDATA
       TOTAL COUNT=       117
```

Listing 8-16 Output Data for the 15-Degree Sweptback Wing by KE-Method

```
 EXAMPLE HA145E: HALF SPAN 15-DEG SWEPT UNTAPERED WING                                                        PAGE    14
   KE-METHOD FLUTTER ANALYSIS, DOUBLET-LATTICE AERO

   0.041 IN AL PLATE W/BEVELLED LEADING AND TRAILING EDGES

                                     O U T P U T   F R O M   G R I D   P O I N T   W E I G H T   G E N E R A T O R
                                                            REFERENCE POINT =       17
                                                                      M O
                              *  4.000018E-02 -2.715799E-20  0.000000E+00  0.000000E+00  0.000000E+00 -1.105025E-01 *
                              * -2.715799E-20  4.000018E-02  0.000000E+00  0.000000E+00  0.000000E+00  2.960875E-02 *
                              *  0.000000E+00  0.000000E+00  4.000018E-02  1.105025E-01 -2.960875E-02  0.000000E+00 *
                              *  0.000000E+00  0.000000E+00  1.105025E-01  4.070250E-01 -1.090611E-01  0.000000E+00 *
                              *  0.000000E+00  0.000000E+00 -2.960875E-02 -1.090611E-01  4.038716E-02  0.000000E+00 *
                              * -1.105025E-01  2.960875E-02  0.000000E+00  0.000000E+00  0.000000E+00  4.474122E-01 *
                                                                       S
                                                    *  1.000000E+00  0.000000E+00  0.000000E+00 *
                                                    *  0.000000E+00  1.000000E+00  0.000000E+00 *
                                                    *  0.000000E+00  0.000000E+00  1.000000E+00 *
                                        DIRECTION
                                   MASS AXIS SYSTEM (S)     MASS              X-C.G.        Y-C.G.        Z-C.G.
                                           X            4.000018E-02      0.000000E+00  2.762550E+00  0.000000E+00
                                           Y            4.000018E-02      7.402154E-01  0.000000E+00  0.000000E+00
                                           Z            4.000018E-02      7.402154E-01  2.762550E+00  0.000000E+00
                                                                      I(S)
                                                    *  1.017562E-01  2.726544E-02  0.000000E+00 *
                                                    *  2.726544E-02  1.847031E-02  0.000000E+00 *
                                                    *  0.000000E+00  0.000000E+00  1.202265E-01 *
                                                                      I(Q)
                                                    *  1.098882E-01                             *
                                                    *                1.033837E-02               *
                                                    *                              1.202265E-01 *
                                                                       Q
                                                    *  9.582864E-01  2.858097E-01  0.000000E+00 *
                                                    * -2.858097E-01  9.582864E-01  0.000000E+00 *
                                                    *  0.000000E+00  0.000000E+00  1.000000E+00 *
```

R E A L   E I G E N V A L U E S

MODE NO.	EXTRACTION ORDER	EIGENVALUE	RADIANS	CYCLES	GENERALIZED MASS	GENERALIZED STIFFNESS
1	1	4.656516E+04	2.157896E+02	3.434399E+01	2.485460E-05	1.157358E+00
2	2	1.741004E+06	1.319471E+03	2.100004E+02	9.088139E-06	1.582249E+01
3	3	2.677549E+06	1.636322E+03	2.604287E+02	8.523229E-06	2.282136E+01
4	4	1.590669E+07	3.988319E+03	6.347607E+02	7.943937E-06	1.263618E+02
5	5	2.676045E+07	5.173050E+03	8.233165E+02	0.0	0.0
6	6	6.705251E+07	8.188560E+03	1.303250E+03	0.0	0.0
7	7	1.020573E+08	1.010234E+04	1.607838E+03	0.0	0.0
8	8	2.060991E+08	1.435615E+04	2.284852E+03	0.0	0.0
9	9	2.839795E+08	1.685169E+04	2.682030E+03	0.0	0.0
10	10	3.717569E+08	1.928100E+04	3.068666E+03	0.0	0.0
11	11	4.330577E+08	2.081004E+04	3.312021E+03	0.0	0.0
12	12	5.752655E+08	2.398469E+04	3.817282E+03	0.0	0.0
13	13	6.478299E+08	2.545250E+04	4.050891E+03	0.0	0.0
14	14	7.371569E+08	2.715063E+04	4.321158E+03	0.0	0.0
15	15	1.062141E+09	3.259050E+04	5.186939E+03	0.0	0.0
16	16	1.340560E+09	3.661366E+04	5.827244E+03	0.0	0.0
17	17	1.504211E+09	3.878416E+04	6.172690E+03	0.0	0.0
18	18	2.016247E+09	4.490264E+04	7.146477E+03	0.0	0.0
19	19	2.896543E+09	5.381954E+04	8.565646E+03	0.0	0.0
20	20	3.734665E+09	6.111191E+04	9.726263E+03	0.0	0.0
21	21	3.846094E+09	6.201689E+04	9.870294E+03	0.0	0.0
22	24	4.477241E+09	6.691219E+04	1.064941E+04	0.0	0.0
23	25	4.639453E+09	6.811353E+04	1.084060E+04	0.0	0.0
24	27	4.942807E+09	7.030509E+04	1.118940E+04	0.0	0.0
25	31	5.256085E+09	7.249886E+04	1.153855E+04	0.0	0.0
26	35	5.759771E+09	7.589316E+04	1.207877E+04	0.0	0.0
27	37	6.100986E+09	7.810880E+04	1.243140E+04	0.0	0.0
28	36	6.657555E+09	8.159384E+04	1.298606E+04	0.0	0.0
29	34	7.332474E+09	8.562987E+04	1.362842E+04	0.0	0.0
30	33	8.441385E+09	9.187702E+04	1.462268E+04	0.0	0.0
31	32	9.166367E+09	9.574114E+04	1.523768E+04	0.0	0.0
32	30	1.070424E+10	1.034613E+05	1.646638E+04	0.0	0.0
33	29	1.173995E+10	1.083510E+05	1.724460E+04	0.0	0.0
34	28	1.259991E+10	1.122493E+05	1.786503E+04	0.0	0.0
35	26	1.455259E+10	1.206341E+05	1.919951E+04	0.0	0.0
36	23	1.897902E+10	1.377644E+05	2.192588E+04	0.0	0.0
37	22	2.018797E+10	1.420844E+05	2.261343E+04	0.0	0.0

Listing 8-16 Output Data for the 15-Degree Sweptback Wing by KE-Method (Continued)

```
EIGENVALUE =  4.656516E+04
    CYCLES =  3.434399E+01         R E A L   E I G E N V E C T O R   N O .          1

POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
       1      G                                     -3.320767E-03
       2      G                                      3.354167E-02
       3      G                                      1.197589E-01
       4      G                                      2.415488E-01
       5      G                                      3.895444E-01
       6      G                                      5.599717E-01
       7      G                                      7.364755E-01
       8      G                                      9.197437E-01
      10      G                                      3.985383E-02
      11      G                                      1.283573E-01
      12      G                                      2.494006E-01
      13      G                                      4.009323E-01
      14      G                                      5.693349E-01
      15      G                                      7.477077E-01
      16      G                                      9.293225E-01
      18      G                                      5.363604E-02
      19      G                                      1.427034E-01
      20      G                                      2.734128E-01
      21      G                                      4.279284E-01
      22      G                                      5.990526E-01
      23      G                                      7.780458E-01
      24      G                                      9.601672E-01
      26      G                                      4.663620E-02
      27      G                                      1.527655E-01
      28      G                                      2.906153E-01
      29      G                                      4.520696E-01
      30      G                                      6.267195E-01
      31      G                                      8.077030E-01
      32      G                                      9.904701E-01
      33      G                                     -3.744976E-03
      34      G                                      4.227901E-02
      35      G                                      1.548405E-01
      36      G                                      2.953975E-01
      37      G                                      4.598230E-01
      38      G                                      6.353986E-01
      39      G                                      8.179794E-01
      40      G                                      1.000000E+00

EIGENVALUE =  1.741004E+06
    CYCLES =  2.100004E+02         R E A L   E I G E N V E C T O R   N O .          2

POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
       1      G                                      1.107332E-02
       2      G                                     -1.414919E-01
       3      G                                     -4.007863E-01
       4      G                                     -6.050646E-01
       5      G                                     -6.624407E-01
       6      G                                     -5.821251E-01
       7      G                                     -3.570982E-01
       8      G                                     -7.326151E-02
      10      G                                     -1.446287E-01
      11      G                                     -3.784626E-01
      12      G                                     -5.368558E-01
      13      G                                     -5.745575E-01
      14      G                                     -4.620206E-01
      15      G                                     -2.318033E-01
      16      G                                      6.338773E-02
      18      G                                     -1.403477E-01
      19      G                                     -2.714325E-01
      20      G                                     -3.485831E-01
      21      G                                     -2.981144E-01
      22      G                                     -1.210224E-01
      23      G                                      1.500928E-01
      24      G                                      4.641854E-01
      26      G                                     -6.794433E-02
      27      G                                     -1.554098E-01
      28      G                                     -1.528570E-01
      29      G                                     -2.636064E-02
      30      G                                      2.173962E-01
      31      G                                      5.304146E-01
      32      G                                      8.653485E-01
      33      G                                      1.004412E-02
      34      G                                     -3.825526E-02
      35      G                                     -1.152495E-01
      36      G                                     -8.781217E-02
      37      G                                      6.338255E-02
      38      G                                      3.312269E-01
      39      G                                      6.570764E-01
      40      G                                      1.000000E+00
```

Listing 8-16 Output Data for the 15-Degree Sweptback Wing by KE-Method (Continued)

```
EIGENVALUE =  2.677549E+06
    CYCLES =  2.604287E+02         R E A L   E I G E N V E C T O R   N O .          3

POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
       1      G                                     2.114405E-03
       2      G                                     1.986178E-02
       3      G                                     6.028288E-02
       4      G                                     1.323192E-01
       5      G                                     2.601770E-01
       6      G                                     4.728811E-01
       7      G                                     7.355465E-01
       8      G                                     1.000000E+00
      10      G                                     2.551326E-03
      11      G                                     1.791453E-02
      12      G                                     5.546072E-02
      13      G                                     1.576512E-01
      14      G                                     3.465791E-01
      15      G                                     5.893692E-01
      16      G                                     8.437764E-01
      18      G                                    -5.833367E-02
      19      G                                    -1.493534E-01
      20      G                                    -2.188800E-01
      21      G                                    -1.930001E-01
      22      G                                    -6.678208E-02
      23      G                                     1.327620E-01
      24      G                                     3.624148E-01
      26      G                                    -1.448625E-01
      27      G                                    -3.904501E-01
      28      G                                    -5.610464E-01
      29      G                                    -6.075832E-01
      30      G                                    -5.242109E-01
      31      G                                    -3.486537E-01
      32      G                                    -1.321460E-01
      33      G                                    -2.928281E-03
      34      G                                    -1.885662E-01
      35      G                                    -4.888113E-01
      36      G                                    -6.918882E-01
      37      G                                    -7.600891E-01
      38      G                                    -6.841900E-01
      39      G                                    -5.152062E-01
      40      G                                    -2.968765E-01

EIGENVALUE =  1.590669E+07
    CYCLES =  6.347607E+02         R E A L   E I G E N V E C T O R   N O .          4

POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
       1      G                                    -2.639108E-02
       2      G                                     3.380127E-01
       3      G                                     7.191586E-01
       4      G                                     6.149204E-01
       5      G                                     8.150127E-02
       6      G                                    -3.522899E-01
       7      G                                    -4.111290E-01
       8      G                                    -5.156524E-02
      10      G                                     3.281422E-01
      11      G                                     6.388384E-01
      12      G                                     4.704424E-01
      13      G                                     1.107625E-02
      14      G                                    -3.550788E-01
      15      G                                    -3.136066E-01
      16      G                                     7.111400E-02
      18      G                                     2.931411E-01
      19      G                                     3.630863E-01
      20      G                                     1.505998E-01
      21      G                                    -2.019493E-01
      22      G                                    -3.253174E-01
      23      G                                    -6.143166E-02
      24      G                                     4.675871E-01
      26      G                                     1.313829E-01
      27      G                                     1.363093E-01
      28      G                                    -1.371148E-01
      29      G                                    -3.879782E-01
      30      G                                    -2.929345E-01
      31      G                                     1.947475E-01
      32      G                                     8.673875E-01
      33      G                                    -1.393048E-02
      34      G                                     8.065992E-02
      35      G                                     6.916270E-02
      36      G                                    -2.318921E-01
      37      G                                    -4.519431E-01
      38      G                                    -2.835256E-01
      39      G                                     2.888194E-01
      40      G                                     1.000000E+00
```

Listing 8-16 Output Data for the 15-Degree Sweptback Wing by KE-Method (Continued)

```
                                          FLUTTER  SUMMARY
POINT =     1     MACH NUMBER =  0.4500     DENSITY RATIO =  9.6700E-01     METHOD = KE

KFREQ            1./KFREQ          VELOCITY           DAMPING           FREQUENCY           COMPLEX   EIGENVALUE
 0.2000        5.0000000E+00     6.7383588E+02     -8.0309570E-02     2.4861040E+02     -3.2339059E+02     8.0665645E+03
 0.1667        5.9998803E+00     8.1385651E+02     -9.6444093E-02     2.5023061E+02     -4.6823199E+02     9.7324424E+03
 0.1429        6.9998603E+00     9.6011792E+02     -1.1731868E-01     2.5302904E+02     -6.7008716E+02     1.1462539E+04
 0.1250        8.0000000E+00     1.1146493E+03     -1.4525376E-01     2.5702975E+02     -9.5884106E+02     1.3271563E+04
 0.1111        9.0000896E+00     1.2800532E+03     -1.8538663E-01     2.6237131E+02     -1.3940487E+03     1.5167494E+04
 0.1000        1.0000000E+01     1.4570992E+03     -2.4710195E-01     2.6879694E+02     -2.0816389E+03     1.7101801E+04

POINT =     2     MACH NUMBER =  0.4500     DENSITY RATIO =  9.6700E-01     METHOD = KE

KFREQ            1./KFREQ          VELOCITY           DAMPING           FREQUENCY           COMPLEX   EIGENVALUE
 0.2000        5.0000000E+00     4.2033994E+02     -7.3245011E-02     1.5508357E+02     -1.8411005E+02     5.0339712E+03
 0.1667        5.9998803E+00     4.5330319E+02     -5.6584969E-02     1.3937387E+02     -1.5359367E+02     5.4331221E+03
 0.1429        6.9998603E+00     4.7559656E+02     -3.1927105E-02     1.2533850E+02     -9.1048523E+01     5.7049785E+03
 0.1250        8.0000000E+00     4.9039053E+02     -1.4126945E-03     1.1308038E+02     -4.1566267E+00     5.8846816E+03
 0.1111        9.0000896E+00     4.9992407E+02      3.3927854E-02     1.0246896E+02      1.0169495E+02     5.9965015E+03
 0.1000        1.0000000E+01     5.0586630E+02      7.4329272E-02     9.3319183E+01      2.2482840E+02     6.0578696E+03

POINT =     3     MACH NUMBER =  0.4500     DENSITY RATIO =  9.6700E-01     METHOD = KE

KFREQ            1./KFREQ          VELOCITY           DAMPING           FREQUENCY           COMPLEX   EIGENVALUE
 0.2000        5.0000000E+00     1.4238643E+03     -3.9331403E-02     5.2533191E+02     -3.3569098E+02     1.7076471E+04
 0.1667        5.9998803E+00     1.5988702E+03     -2.8735427E-02     4.9159314E+02     -2.7552316E+02     1.9180506E+04
 0.1429        6.9998603E+00     1.7381207E+03     -1.1333041E-02     4.5806354E+02     -1.1817968E+02     2.0856445E+04
 0.1250        8.0000000E+00     1.8456505E+03      1.4551986E-02     4.2559317E+02      1.6112596E+02     2.2146047E+04
 0.1111        9.0000896E+00     1.9268026E+03      5.3239781E-02     3.9493491E+02      6.1440735E+02     2.3097105E+04
 0.1000        1.0000000E+01     1.9934751E+03      1.1295156E-01     3.6774432E+02      1.3403313E+03     2.3808307E+04

POINT =     4     MACH NUMBER =  0.4500     DENSITY RATIO =  9.6700E-01     METHOD = KE

KFREQ            1./KFREQ          VELOCITY           DAMPING           FREQUENCY           COMPLEX   EIGENVALUE
 0.2000        5.0000000E+00     9.3989601E+01     -1.0171605E-01     3.4677273E+01     -5.6993584E+01     1.1235320E+03
 0.1667        5.9998803E+00     1.1353393E+02     -1.2407344E-01     3.4907459E+01     -8.3715805E+01     1.3546294E+03
 0.1429        6.9998603E+00     1.3351437E+02     -1.4841494E-01     3.5186317E+01     -1.1728425E+02     1.5891471E+03
 0.1250        8.0000000E+00     1.5403619E+02     -1.7534544E-01     3.5519588E+01     -1.5901660E+02     1.8275884E+03
 0.1111        9.0000896E+00     1.7522746E+02     -2.0578188E-01     3.5916210E+01     -2.1081007E+02     2.0703347E+03
 0.1000        1.0000000E+01     1.9723370E+02     -2.4094324E-01     3.6384491E+01     -2.7523788E+02     2.3173606E+03
```

Low Supersonic Flutter Analysis of the 15-Degree Sweptback Wing Using Mach Box Aerodynamics (Example HA145F)

Wind tunnel flutter tests of untapered aluminum plate wings with 15 degrees of sweep were reported by Tuovila and McCarty (1955) [Reference 60]. One supersonic test Mach number was $m = 1.3$, and this case is chosen to illustrate the use of the Mach Box aerodynamic method. A similar aluminum wing was tested at a subsonic Mach number of $m = 0.45$ and was the subject of the previous Example HA145E. The present example uses the same adjusted structural model as in Example HA145E because both the model weights and second vibration frequencies are identical and the same structural damping coefficient of $g = 0.01$ has been assumed. The PK-method of flutter analysis will be used to predict the flutter speed and frequency at the test density and Mach number.

The new aerodynamic data begins with the AERO entry that specifies the reference parameters and symmetry conditions for the flutter analysis; the reference chord is 2.07055 in, sea-level density is chosen, and symmetry about the wind tunnel wall is assumed. Mach Box aerodynamics are specified on the CAERO3 and PAERO3 and related entries. The CAERO3 entry specifies certain intermediate sets of planform coordinates for splining on the wing and two control surfaces in its LISTW, LISTC1 and LISTC2 fields by reference to AEFACT entries, and its planform geometry on the continuation entry. These intermediate coordinates are selected at points that are representative of the modal deflections that determine the supersonic aerodynamic generalized forces. These points are interconnected with specified structural grid points by a user-selected spline. These points are also automatically interconnected (within the AMG module) by a surface spline to the Mach box centers that move with the Mach number. In this example LISTW on the CAERO3 101 entry refers to the AEFACT 11 entry, which lists 20 (x,y) pairs of coordinates. There are no control surfaces. The 20 (x,y) pairs are selected from the set of structural grid points for convenience, and since they are somewhat arbitrary, the grid point coordinates are rounded off to two decimals. The entry PAERO3 1 defines the number of chordwise Mach boxes between the upstream and downstream extremes of the planform, in this case 11.

The user-specified spline to interconnect the Mach Box (x,y) pairs to the structural grid points is the surface spline SPLINE1 100. It connects the region specified by the range BOX1 = 101 through BOX2 = 120 on CAERO3 101 to the set of 20 structural grid points SETG = 100 listed on SET1 100. BOXi is a misnomer in the Mach Box method since it only refers to the ID of an (x,y) pair. BOX1 = 101 through BOX2 = 120 includes all of the (x,y) pairs on the AEFACT 11 entry. The MKAERO1 entry prescribes the aerodynamic database at Mach 1.3 and $k = 0.03$, 0.04, and 0.05 for subsequent interpolation in the PK-flutter analysis to include the experimental flutter reduced frequency, which was 0.0432.

The vibration analysis is performed via EIGR 10 that requests the Modified Givens Eigenvalue Extraction method (MGIV) and six modes to be found and normalized on their maximum components. PARAM,OPPHIPA,1, along with a DISP request in the Case Control Section, provides the vibration modes at the structural and aerodynamic grid points in the output.

The PARAM,LMODES entry specifies that the four lowest frequencies of the six vibration modes be used in the flutter analysis. The FLUTTER entry specifies the PK-method of analysis at the test density ratio on FLFACT 1, the test Mach number on FLFACT 2, and for the series of velocities on FLFACT 3 entries. Since no negative velocity is given on the FLFACT 3 entry, no flutter modes will be calculated. The FLUTTER entry also specifies three flutter solutions be output from the four mode formulation. The PARAM,VREF = 12.0 converts the analysis units of velocity from in/s to ft/s in the Flutter Summary. The ENDDATA entry completes the Bulk Data Section.

Case Control Commands

The Case Control Section begins with three title entries. ECHO = BOTH lists both the annotated and sorted Bulk Data entries. SPC = 1 provides the restraints on the wing root and on the plate element in-plane rotations. SDAMP = 2000 invokes the tabulated damping data. METHOD = 10 selects the method of vibration analysis, and FLUTTER = 30 chooses the method of flutter analysis. The DISP = ALL entry (and PARAM,OPPHIPA,1) provides the modal displacements at both the structural and aerodynamic grid points.

The OUTPUT(PLOT) entry identifies the plot packet for the structure plotter. The spacing in the title is specified by CSCALE 2.0. The CQUAD4 structural elements will be plotted. The FIND entry prescribes the origin and scales of the plots. The PLOT entry requests that the vibration modes be overlaid on the undeformed structure. The OUTPUT(XYOUT) entry identifies the plot packet for xy-plots. The first several statements are optional and define the plot frame and plot titles. The xy-plot request is for the first three flutter modes. Plots of damping on the top frame and frequency on the bottom frame, both versus velocity, will be plotted. BEGIN BULK concludes the Case Control Section.

The problem identification ID MSC, HA145F begins the Executive Control Section. TIME 5 restricts the CPU time to 5.0 minutes. SOL 145 calls for the Structured Aerodynamic Flutter DMAP sequence. CEND completes the Executive Control Section.

Output

The input data are shown in Listing 8-17, the sorted Bulk Data entries are in Listing 8-18, and the representative output data follow in Listing 8-19. The results shown are discussed below.

The output begins with the vibration results, which are given for the six modes requested. The results agree with those in the previous Example HA145E where four modes were requested. The vibration modes are not shown because they are identical with Example HA145E. The next two items of output are a summary of the planform geometry data for the points and lines shown in the description of the PAERO3, 814 and a graphic display of the Mach boxes on and off the planform for the Mach number under consideration. At other Mach numbers the distribution of Mach boxes will be different, and the display provides a guide to indicate if a sufficient number of Mach boxes are on the main and control surfaces. The Flutter Summaries for the three flutter modes requested complete the output shown. The flutter damping and frequency versus velocity curves for the second mode (Point 2) are plotted in Figure 8-10 along with the experimental data. The first and third modes are stable while the second mode goes unstable at $V_f = 1582 \text{ ft/s}$ with a frequency of $f_f = 128 \text{ Hz}$ for the four mode solution. The test results were $V_f = 1280 \text{ ft/s}$ and $f_f = 102 \text{ Hz}$.

The reason for the unconservative prediction here is not known; the Mach Box method has been shown to be conservative in another application by Pendleton, French, and Noll (1987) [Reference 37]. There is, however, an unconservative aspect of linearized aerodynamic theory at supersonic speeds that must be mentioned. A consequence of neglecting thickness effects at supersonic speeds is an aft location of the aerodynamic center. These effects of thickness are included in Piston Theory but that theory is only valid at high Mach numbers. The correction matrix (WKK) in (2-21) might be used to adjust the Mach Box pressure solution so that the line of local aerodynamic centers moves forward by an amount determined by some appropriate aerodynamic method for thick wings in steady supersonic flow. The correction matrix might compensate for this unconservative feature of the Mach Box method. However, in this example the thin plate airfoil has only 2% thickness, and thickness effects alone do not explain the magnitude of the discrepancy between the predicted and measured flutter speeds observed here.

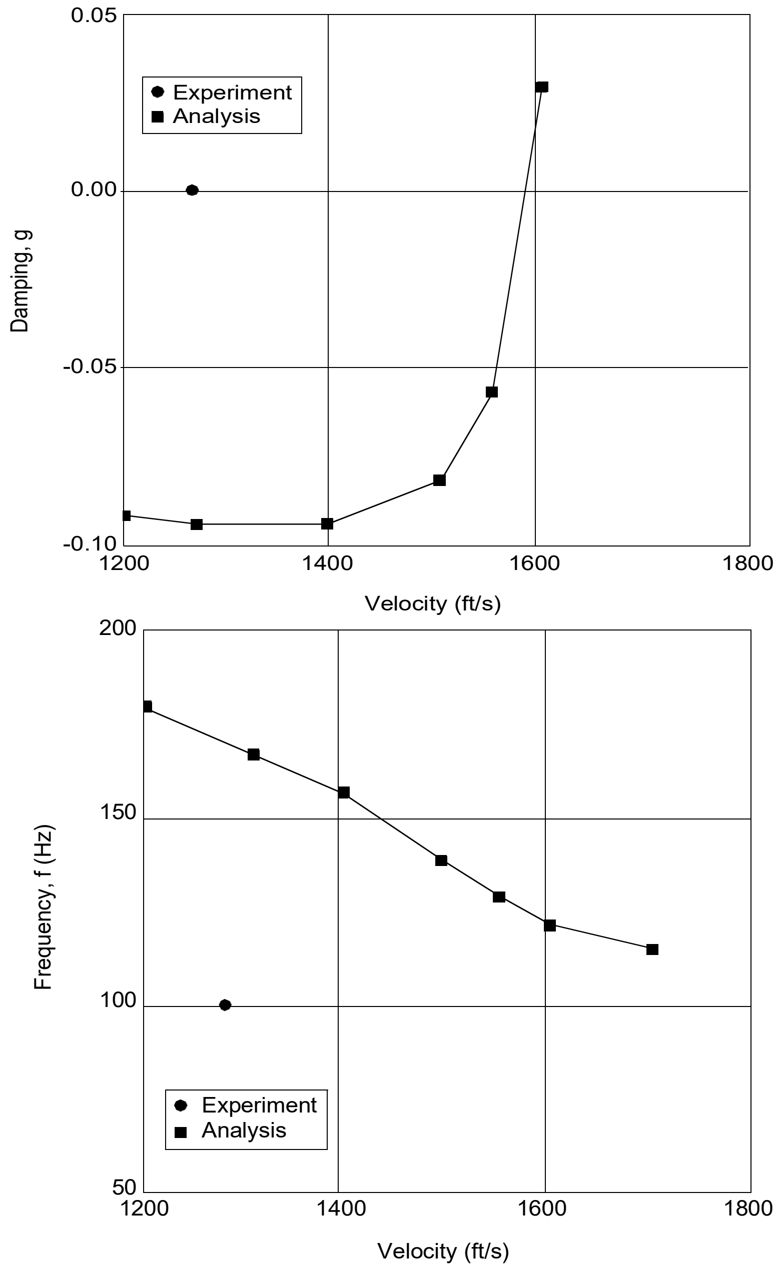

Figure 8-10 Low Supersonic Flutter Damping and Frequency Curves for Sweptback Wing Model by Mach Box Method

Listing 8-17 Input Data for the 15-Degree Sweptback Wing with Mach Box Aerodynamics

```
    N A S T R A N    E X E C U T I V E    C O N T R O L    D E C K    E C H O
ID MSC, HA145F
$$$$$$$$ HANDBOOK FOR AEROELASTIC ANALYSIS EXAMPLE HA145F       $$$$$$$$        $
$                                                                               $
$       MODEL DESCRIPTION       MODEL A OF NASA TN D-1824                       $
$                               HALF SPAN 15 DEGREE SWEPT WING                  $
$                               28 QUAD4 PANEL MODEL                            $
$                                                                               $
$       SOLUTION                PK-FLUTTER ANALYSIS METHOD                      $
$                               USING MACH BOX METHOD                           $
$                               AERODYNAMICS AT MACH NO. 1.3                    $
$                                                                               $
$       OUTPUT                  PLOTS OF VIBRATION MODES AND X-Y                $
$                               PLOTS OF V-G FLUTTER DATA                       $
$                                                                               $
$$$$$$$$                                                        $$$$$$$$        $
TIME 5  $ CPU TIME IN MINUTES
SOL 145  $ FLUTTER ANALYSIS
CEND
```

```
EXAMPLE HA145F: HALF SPAN 15-DEG SWEPT UNTAPERED WING                OCTOBER  29, 1993  MSC/NASTRAN  10/28/93   PAGE     2
 PK-METHOD OF FLUTTER ANALYSIS, MACH BOX AERO
 0.041 IN AL PLATE W/BEVELLED LEADING AND TRAILING EDGES
                                 C A S E    C O N T R O L   D E C K   E C H O
            CARD
            COUNT
             1      TITLE = EXAMPLE HA145F: HALF SPAN 15-DEG SWEPT UNTAPERED WING
             2      SUBT  = PK-METHOD OF FLUTTER ANALYSIS, MACH BOX AERO
             3      LABEL = 0.041 IN AL PLATE W/BEVELLED LEADING AND TRAILING EDGES
             4        ECHO    = BOTH
             5        SPC     = 1   $
             6        SDAMP   = 2000
             7        METHOD  = 10  $ MODIFIED GIVENS
             8        FMETHOD = 30  $ PK-FLUTTER METHOD
             9        DISP    = ALL $ PRINT VIBRATION MODES
            10      OUTPUT(PLOT)
            11        CSCALE 2.0
            12        PLOTTER NASTRAN
            13        SET 1   = QUAD4
            14        PTITLE = STRUCTURAL ELEMENTS
            15        FIND SCALE, ORIGIN 1, SET 1
            16        PLOT MODAL 0
            17      OUTPUT (XYOUT)
            18        CSCALE 2.0
            19        PLOTTER NASTRAN
            20        CURVELINESYMBOL = -6
            21        YTTITLE = DAMPING  G
            22        YBTITLE = FREQUENCY  F  HZ
            23        XTITLE  = VELOCITY  V (IN/SEC)
            24        XTGRID LINES = YES
            25        XBGRID LINES = YES
            26        YTGRID LINES = YES
            27        YBGRID LINES = YES
            28        UPPER TICS  = -1
            29        TRIGHT TICS = -1
            30        BRIGHT TICS = -1
            31        XYPLOT VG / 1(G,F) 2(G,F) 3(G,F)
            32      BEGIN BULK
```

Listing 8-17 Input Data for the 15-Degree Sweptback Wing with Mach Box Aerodynamics (Continued)

```
EXAMPLE HA145F: HALF SPAN 15-DEG SWEPT UNTAPERED WING               OCTOBER  29, 1993  MSC/NASTRAN  10/28/93   PAGE     3
 PK-METHOD OF FLUTTER ANALYSIS, MACH BOX AERO
 0.041 IN AL PLATE W/BEVELLED LEADING AND TRAILING EDGES
                              I N P U T   B U L K   D A T A   D E C K   E C H O
                 .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                 $*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
                 $                                                                    $
                 $        THE ANNOTATIONS IN THIS INPUT DECK ARE INTENDED TO          $
                 $        EXPLAIN THE DATA ON THE CARD IMAGES FOR THIS                $
                 $        EXAMPLE WITHOUT REFERENCE TO THE VARIOUS MANUALS WHERE      $
                 $        MORE GENERAL DESCRIPTIONS WILL BE FOUND.                    $
                 $                                                                    $
                 $*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
                 $                                                                    $
                 INCLUDE PLATE_STRUCT.DAT
                 $                                                                    $
                 $                 * * MASS AND INERTIA PROPERTIES * *                $
                 $                                                                    $
                 $        THE MAT1 ENTRY DEFINES THE MATERIAL PROPERTIES FOR LINEAR,  $
                 $        TEMPERATURE-INDEPENDENT, ISOTROPIC MATERIALS.  IT LISTS     $
                 $        YOUNGS MODULUS, THE SHEAR MODULUS, POISSONS RATIO,          $
                 $        MASS DENSITY, THERMAL EXPANSION COEFFICIENT AND STRUCTURAL  $
                 $        ELEMENT DAMPING.                                            $
                 $                                                                    $
                 $       MID     E       G       NU      RHO     A       TREF    GE
                 MAT1    1       9.2418+63.4993+6        0.097464
                 $                                                                    $
                 $                    * * STRUCTURAL CONSTRAINTS * *                  $
                 $                                                                    $
                 $        THE SPC1 ENTRY DEFINES SETS OF SINGLE-POINT CONSTRAINTS.    $
                 $        IT LISTS THE DOF COMPONENTS TO BE CONSTRAINED AND THE GRID  $
                 $        POINT NO.                                                   $
                 $                                                                    $
                 $       SID     C       G1      G2      ETC
                 SPC1    1       12345   9
                 SPC1    1       12345   25
                 SPC1    1       6       1       THRU    40
                 $                                                                    $
                 $        THE ASET1 ENTRY DEFINES DOFS THAT THE USER DESIRES TO BE    $
                 $        INDEPENDENT.  IT LISTS THE DOF COMPONENT NUMBERS AND THE    $
                 $        GRID ID NO.S.                                               $
                 $                                                                    $
                 $       V       ID1     THRU    ID2
                 ASET1   3        1      THRU     8
                 ASET1   3       10      THRU    24
                 ASET1   3       26      THRU    40
                 $                                                                    $
                 $                      *  STRUCTURAL DAMPING *                       $
                 $                                                                    $
                 $        THE PARAMETER KDAMP DETERMINES THE MANNER OF INCLUDING      $
                 $        STRUCTURAL DAMPING IN THE EQUATIONS OF MOTION (SEE THE      $
                 $        HANDBOOK FOR DYNAMIC ANALYSIS, SECTION 3.2.2).  IF SET TO   $
                 $        -1, MODAL STRUCTURAL DAMPING IS INCLUDED AS THE IMAGINARY   $
                 $        PART OF A COMPLEX STIFFNESS MATRIX.                         $
                 $                                                                    $
                 $       N       V1      V2                                           $
                 PARAM   KDAMP   +1
                 $                                                                    $
                 $        THE TABDMP1 ENTRY AND TABLE DEFINE MODAL DAMPING AS A       $
                 $        TABULAR FUNCTION OF FREQUENCY.  THE DAMPING VALUES ARE      $
                 $        LINEAR BETWEEN THE FREQUENCY AND DAMPING PAIRS AND ARE      $
                 $        ZERO OUTSIDE THE TABULATED FREQUENCY RANGE.                 $
                 $                                                                    $
                 $       ID                                                           +TDP
                 TABDMP1 2000                                                         +T2000
                 $       F1      G1      F2      G2      ETC             ENDT
                 +T2000  0.0     0.01    1000.0  0.01    ENDT
                 $                                                                    $
```

Listing 8-17 Input Data for the 15-Degree Sweptback Wing with Mach Box Aerodynamics (Continued)

```
$                      * * * AERODYNAMIC DATA * * *                      $
$                                                                        $
$                          (LB-IN-SEC SYSTEM)                            $
$                                                                        $
$        THE AERO ENTRY SPECIFIES THE AERO COORDINATE SYSTEM, THE        $
$        VELOCITY (USED FOR DATA RECOVERY), THE REFERENCE CHORD          $
$        AND FLUID DENSITY, PLUS SYMMETRY KEYS.  SYMXZ=0 INDICATES       $
$        THAT THE MODEL IS MOUNTED AS AN ISOLATED WING; SYMXY=0          $
$        INDICATES THAT THE MODEL IS MOUNTED FAR ENOUGH FROM THE         $
$        FLOOR SO THAT REFLECTION EFFECTS ARE NEGLIGIBLE.                $
$                                                                        $
$       ACSID   VELOCITY REFC    RHOREF  SYMXZ   SYMXY
AERO    0                2.07055 1.145-7 1
$                                                                        $
$        THE CAERO3 ENTRY DEFINES PANEL ELEMENTS FOR THE MACH BOX        $
$        METHOD: PID REFERS TO PROPERTIES DEFINED ON A PAERO3            $
$        ENTRY, CP REFERS TO THE COORDINATE SYSTEM OF POINTS 1 AND 4,    $
$        LISTW IS THE ID OF AN AEFACT ENTRY ON WHICH ARE LISTED THE      $
$        (X,Y) COORDINATES OF AN INTERMEDIATE SET OF POINTS ON THE       $
$        WING, OPTIMALLY, THE MINIMUM NUMBER REQUIRED TO DEFINE THE      $
$        MODE SHAPES AND CHORDWISE SLOPES OF ALL THE MODES USED IN       $
$        THE ANALYSIS.  THE INTERMEDIATE SET OF POINTS AND DISPLACE-     $
$        MENTS IS THEN USED TO GENERATE INTERPOLATED DOWNWASHES AT       $
$        ANY REQUIRED MACH NUMBER.  LISTC1 AND LISTC2 ARE CORRES-        $
$        PONDING AEFACT ENTRIES WHEN CONTROL SURFACES ARE PRESENT.       $
$        THE CONTINUATION ENTRY LISTS THE COORDINATES AND CHORD AT       $
$        POINTS 1 AND 4.                                                 $
$                                                                        $
$       EID     PID     CP      LISTW   LISTC1  LISTC2
CAERO3  101     1       0       11                                      +CA101
$       X1      Y1      Z1      X12     X4      Y4      Z4      X43
+CA101  0.0     0.0     0.0     2.07055 1.48044 5.5251  0.0     2.07055
$                                                                        $
$        THE NUMBER OF X,Y PAIRS ON THE AEFACT ENTRY MUST EQUAL THE      $
$        NUMBER OF POINTS SPECIFIED IN FIELDS 4 AND 5 OF ITS ASSOCIATED  $
$        SPLINE ENTRY (IN THIS CASE SPLINE1,100).                        $
$                                                                        $
$               X1      Y1      X2      Y2      ETC                      $
AEFACT  11      0.21    0.79    0.63    2.37    1.06    3.95    1.48    +AEF1
+AEF1   5.53    0.26    0.0     0.68    1.58    1.10    3.16    1.53    +AEF2
+AEF2   4.74    1.25    0.79    1.67    2.37    2.09    3.95    2.52    +AEF3
+AEF3   5.53    1.81    0.0     2.23    1.58    2.66    3.16    3.08    +AEF4
+AEF4   4.74    2.28    0.79    2.71    2.37    3.13    3.95    3.55    +AEF5
+AEF5   5.53
$                                                                        $
$        THE PAERO3 ENTRY DEFINES THE NUMBER OF CHORDWISE BOXES          $
$        BETWEEN THE FOREMOST AND AFTMOST POINTS OF THE CONFIGUR-        $
$        ATION AND THE NUMBER OF CONTROL SURFACES.  IN THE CASE WHEN     $
$        CONTROL SURFACES ARE PRESENT THE COORDINATES OF THEIR           $
$        CORNERS ARE LISTED.                                             $
$                                                                        $
$       PID     NBOX    NCTRL
PAERO3  1       11      0
$                                                                        $
$                  * SURFACE SPLINE FIT ON THE WING *                    $
$                                                                        $
$        THE SPLINE1 ENTRY DEFINES A SURFACE SPLINE FOR INTERPO-         $
$        LATING OUT-OF-PLANE DISPLACEMENTS FROM THE STRUCTURAL           $
$        GRID POINTS ON THE SETG ENTRY TO THE REGION DEFINED BY          $
$        AERODYNAMIC BOXES 101 THRU 109 OF THE REGION ON THE             $
$        CAERO1 ENTRY.  DZ=0 SPECIFIES THAT NO SMOOTHING OF THE          $
$        SPLINE IS TO BE IMPOSED.                                        $
$                                                                        $
$        IN SUPERSONIC CASES, BOX1 AND BOX2 ARE MISNOMERS; INSTEAD,      $
$        THE DATA SPECIFY FIRST AND LAST POINT NUMBERS GENERATED BY      $
$        THE CAERO3 ENTRY, THE FIRST NUMBER BEING THE ID NUMBER OF THE   $
$        CAERO3 ENTRY AND THE LAST ONE BEING CONSISTENT WITH SEQUENTIAL  $
$        NUMBERING OF THE X,Y PAIRS SPECIFIED BY THE CAERO3 ENTRY.       $
$        THE SPLINE DETERMINED FROM EACH SETG IS USED TO GENERATE        $
$        DEFLECTIONS AT THESE GIVEN INTERMEDIATE POINTS.                 $
$                                                                        $
$       EID     CAERO   BOX1    BOX2    SETG    DZ
SPLINE1 100     101     101     120     100     0.0
$                                                                        $
$        THE SET1 ENTRY DEFINES THE SET OF STRUCTURAL GRID POINTS TO     $
$        BE USED BY THE SURFACE SPLINE FOR INTERPOLATION.                $
$                                                                        $
$       SID     G1      G2      ETC
SET1    100     2       4       6       8       9       11      13      +S1
+S1     15      18      20      22      24      25      27      29      +S2
+S2     31      34      36      38      40
$                                                                        $
```

Listing 8-17 Input Data for the 15-Degree Sweptback Wing with Mach Box Aerodynamics (Continued)

```
$                      * * AERODYNAMIC DATABASE * *                     $
$                                                                       $
$        ALL COMBINATIONS OF MACH NUMBER AND REDUCED FREQUENCY LISTED   $
$        ON THE MKAERO1 ENTRY AND ITS CONTINUATION ENTRY WILL BE USED   $
$        TO GENERATE GENERALIZED AERO FORCE MATRICES.                   $
$                                                                       $
$       M1      M2      M3      ETC
MKAERO1 1.3                                                             +MK
$       K1      K2      K3      K4      ETC
+MK     .03     .04     .05
$                                                                       $
$                      * * VIBRATION ANALYSIS * *                       $
$                                                                       $
$        THE EIGR ENTRY SPECIFIES THE METHOD OF EXTRACTING THE EIGEN-   $
$        SOLUTIONS OF THE STRUCTURE. IN THIS CASE THE                   $
$        MODIFIED GIVENS METHOD.  THREE MODES ARE DESIRED, NORMAL-      $
$        IZED ON THE MAXIMUM DISPLACEMENTS.                             $
$                                                                       $
$       SID     METHOD  F1      F2              NO                      $
EIGR    10      MGIV                             6                      +ER
$       NORM                                                            $
+ER     MAX
$                                                                       $
$        OPPHIPA = 1 (WHEN ACCOMPANIED BY A DISPLACEMENT REQUEST IN     $
$        THE CASE CONTROL DECK), WILL PRODUCE THE VIBRATION MODE        $
$        DISPLACEMENTS IN THE OUTPUT.                                   $
$                                                                       $
PARAM   OPPHIPA 1
$                                                                       $
$                       * * FLUTTER ANALYSIS * *                        $
$                                                                       $
$        THE PARAM,LMODES,N ENTRY SPECIFIES THAT N MODES ARE TO BE      $
$        USED IN THE FLUTTER ANALYSIS.                                  $
$                                                                       $
PARAM   LMODES  4
$                                                                       $
$        THE FLUTTER ENTRY DEFINES THE METHOD OF SOLUTION, IDENTIFIES   $
$        THE FLFACT ENTRIES THAT FOLL0W, SPECIFIES THE INTERPOLATION    $
$        METHOD, THE NUMBER OF ROOTS DESIRED IN THE OUTPUT AND THE      $
$        CRITERION FOR CONVERGENCE.                                     $
$                                                                       $
$        SID    METHOD  DENS    MACH    RFRQ    IMETH   NVALUE  EPS     $
FLUTTER 30      PK      1       2       3       L       3
$                                                                       $
$        FLFACT ENTRIES ARE USED TO SPECIFY DENSITY RATIOS, MACH NOS    $
$        AND REDUCED FREQUENCIES/VELOCITIES FOR FLUTTER ANALYSES.       $
$                                                                       $
$       SID     F1      F2      F3      F4      F5      F6      F7      $
FLFACT  1       .20606                                                  DENSITY
FLFACT  2       1.3                                                     MACH NO
FLFACT  3       14400.  15600.  16800.  18000.  19200.  20400.          VELOCITY
$                                                                       $
$        THE PARAMETER VREF IS USED TO SCALE THE ANALYSIS UNITS OF      $
$        VELOCITY, HERE IN/S, TO THE UNITS DESIRED IN THE OUTPUT        $
$        FLUTTER SUMMARY TABLES, FT/S.                                  $
$                                                                       $
PARAM   VREF    12.0
$                                                                       $
ENDDATA
INPUT BULK CARD ENTRY COUNT =     332
```

Listing 8-18 Sorted Bulk Data for the 15-Degree Sweptback Wing with Mach Box Aerodynamics

```
EXAMPLE HA145F: HALF SPAN 15-DEG SWEPT UNTAPERED WING                  OCTOBER  29, 1993  MSC/NASTRAN  10/28/93   PAGE    10
  PK-METHOD OF FLUTTER ANALYSIS, MACH BOX AERO

 0.041 IN AL PLATE W/BEVELLED LEADING AND TRAILING EDGES

                                              S O R T E D   B U L K   D A T A   E C H O

             CARD
             COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                1-        AEFACT  11      0.21    0.79    0.63    2.37    1.06    3.95    1.48    +AEF1
                2-        +AEF1   5.53    0.26    0.0     0.68    1.58    1.10    3.16    1.53    +AEF2
                3-        +AEF2   4.74    1.25    0.79    1.67    2.37    2.09    3.95    2.52    +AEF3
                4-        +AEF3   5.53    1.81    0.0     2.23    1.58    2.66    3.16    3.08    +AEF4
                5-        +AEF4   4.74    2.28    0.79    2.71    2.37    3.13    3.95    3.55    +AEF5
                6-        +AEF5   5.53
                7-        AERO    0               2.07055 1.145-7 1
                8-        ASET1   3       1       THRU    8
                9-        ASET1   3       10      THRU    24
               10-        ASET1   3       26      THRU    40
               11-        CAERO3  101     1       0       11                                      +CA101
               12-        +CA101  0.0     0.0     0.0     2.07055 1.48044 5.5251  0.0     2.07055
               13-        CQUAD4  1       1       1       2       10      9                       +M00000
               14-        +M00000                 0.0     0.0     .041    .041
               15-        CQUAD4  2       1       2       3       11      10                      +M00001
               16-        +M00001                 0.0     0.0     .041    .041
               17-        CQUAD4  3       1       3       4       12      11                      +M00002
               18-        +M00002                 0.0     0.0     .041    .041
               19-        CQUAD4  4       1       4       5       13      12                      +M00003
               20-        +M00003                 0.0     0.0     .041    .041
               21-        CQUAD4  5       1       5       6       14      13                      +M00004
               22-        +M00004                 0.0     0.0     .041    .041
               23-        CQUAD4  6       1       6       7       15      14                      +M00005
               24-        +M00005                 0.0     0.0     .041    .041
               25-        CQUAD4  7       1       7       8       16      15                      +M00006
               26-        +M00006                 0.0     0.0     .041    .041
               27-        CQUAD4  8       1       9       10      18      17
               28-        CQUAD4  9       1       10      11      19      18
               29-        CQUAD4  10      1       11      12      20      19
               30-        CQUAD4  11      1       12      13      21      20
               31-        CQUAD4  12      1       13      14      22      21
               32-        CQUAD4  13      1       14      15      23      22
               33-        CQUAD4  14      1       15      16      24      23
               34-        CQUAD4  15      1       17      18      26      25
               35-        CQUAD4  16      1       18      19      27      26
               36-        CQUAD4  17      1       19      20      28      27
               37-        CQUAD4  18      1       20      21      29      28
               38-        CQUAD4  19      1       21      22      30      29
               39-        CQUAD4  20      1       22      23      31      30
               40-        CQUAD4  21      1       23      24      32      31
               41-        CQUAD4  22      1       25      26      34      33                      +M00007
               42-        +M00007                 .041    .041    0.0     0.0
               43-        CQUAD4  23      1       26      27      35      34                      +M00008
               44-        +M00008                 .041    .041    0.0     0.0
               45-        CQUAD4  24      1       27      28      36      35                      +M00009
               46-        +M00009                 .041    .041    0.0     0.0
               47-        CQUAD4  25      1       28      29      37      36                      +M00010
               48-        +M00010                 .041    .041    0.0     0.0
               49-        CQUAD4  26      1       29      30      38      37                      +M00011
               50-        +M00011                 .041    .041    0.0     0.0
               51-        CQUAD4  27      1       30      31      39      38                      +M00012
               52-        +M00012                 .041    .041    0.0     0.0
               53-        CQUAD4  28      1       31      32      40      39                      +M00013
               54-        +M00013                 .041    .041    0.0     0.0
               55-        EIGR    10      MGIV                            6                       +ER
               56-        +ER     MAX
               57-        FLFACT  1       .20606                                                  DENSITY
               58-        FLFACT  2       1.3                                                     MACH NO
               59-        FLFACT  3       14400.  15600.  16800.  18000.  19200.  20400.          VELOCITY
               60-        FLUTTER 30      PK      1       2       3       L       3
               61-        GRID    1               0.0     0.0     0.0
               62-        GRID    2               .211491 .7893   0.0
               63-        GRID    3               .422983 1.5786  0.0
               64-        GRID    4               .634474 2.3679  0.0
               65-        GRID    5               .845966 3.1572  0.0
```

Listing 8-18 Sorted Bulk Data for the 15-Degree Sweptback Wing with Mach Box Aerodynamics (Continued)

```
  66-        GRID    6               1.05746 3.9465  0.0
  67-        GRID    7               1.26895 4.7358  0.0
  68-        GRID    8               1.48044 5.5251  0.0
  69-        GRID    9               .258819 0.0     0.0
  70-        GRID    10              .47031  .7893   0.0
  71-        GRID    11              .681802 1.5786  0.0
  72-        GRID    12              .893293 2.3679  0.0
  73-        GRID    13              1.10478 3.1572  0.0
  74-        GRID    14              1.31628 3.9465  0.0
  75-        GRID    15              1.52777 4.7358  0.0
  76-        GRID    16              1.73926 5.5251  0.0
  77-        GRID    17              1.03528 0.0     0.0
  78-        GRID    18              1.24677 .7893   0.0
  79-        GRID    19              1.45826 1.5786  0.0
  80-        GRID    20              1.66975 2.3679  0.0
  81-        GRID    21              1.88124 3.1572  0.0
  82-        GRID    22              2.09273 3.9465  0.0
  83-        GRID    23              2.30422 4.7358  0.0
  84-        GRID    24              2.51572 5.5251  0.0
  85-        GRID    25              1.81173 0.0     0.0
  86-        GRID    26              2.02322 .7893   0.0
  87-        GRID    27              2.23471 1.5786  0.0
  88-        GRID    28              2.44621 2.3679  0.0
  89-        GRID    29              2.6577  3.1572  0.0
  90-        GRID    30              2.86919 3.9465  0.0
  91-        GRID    31              3.08068 4.7358  0.0
  92-        GRID    32              3.29217 5.5251  0.0
  93-        GRID    33              2.07055 0.0     0.0
  94-        GRID    34              2.28204 .7893   0.0
  95-        GRID    35              2.49353 1.5786  0.0
  96-        GRID    36              2.70502 2.3679  0.0
  97-        GRID    37              2.91652 3.1572  0.0
  98-        GRID    38              3.12801 3.9465  0.0
  99-        GRID    39              3.3395  4.7358  0.0
 100-        GRID    40              3.55099 5.5251  0.0
 101-        MAT1    1       9.2418+63.4993+6        0.097464
 102-        MKAERO1 1.3                                                             +MK
 103-        +MK     .03     .04     .05
 104-        PAERO3  1       11      0
 105-        PARAM   COUPMASS1
 106-        PARAM   KDAMP   +1
 107-        PARAM   LMODES  4
 108-        PARAM   OPPHIPA 1
 109-        PARAM   VREF    12.0
 110-        PARAM   WTMASS  .0025901
 111-        PSHELL  1       1       .041    1               1
 112-        SET1    100     2       4       6       8       9       11      13      +S1
 113-        +S1     15      18      20      22      24      25      27      29      +S2
 114-        +S2     31      34      36      38      40
 115-        SPC1    1       6       1       THRU    40
 116-        SPC1    1       12345   9
 117-        SPC1    1       12345   25
 118-        SPLINE1 100     101     101     120     100     0.0
 119-        TABDMP1 2000                                                            +T2000
 120-        +T2000  0.0     0.01    1000.0  0.01    ENDT
             ENDDATA
       TOTAL COUNT=      121
```

Listing 8-19 Output for the 15-Degree Sweptback Wing with Mach Box Aerodynamics

```
                                                R E A L   E I G E N V A L U E S
   MODE    EXTRACTION      EIGENVALUE            RADIANS             CYCLES            GENERALIZED         GENERALIZED
    NO.       ORDER                                                                         MASS              STIFFNESS
        1         1        4.656516E+04        2.157896E+02        3.434399E+01        2.485460E-05        1.157358E+00
        2         2        1.741003E+06        1.319471E+03        2.100003E+02        9.088159E-06        1.582251E+01
        3         3        2.677548E+06        1.636322E+03        2.604286E+02        8.523231E-06        2.282136E+01
        4         4        1.590605E+07        3.988239E+03        6.347479E+02        7.944785E-06        1.263701E+02
        5         5        2.676011E+07        5.173018E+03        8.233114E+02        8.134972E-06        2.176928E+02
        6         6        6.703381E+07        8.187417E+03        1.303068E+03        4.671878E-06        3.131738E+02
        7         7        1.020194E+08        1.010046E+04        1.607539E+03        0.0                 0.0
        8         8        2.059570E+08        1.435120E+04        2.284065E+03        0.0                 0.0
        9         9        2.830802E+08        1.682499E+04        2.677780E+03        0.0                 0.0
       10        10        3.717334E+08        1.928039E+04        3.068569E+03        0.0                 0.0

                                      SUPERSONIC MACH BOX PROGRAM
                                              CONTROL DATA
                    F         CNTRL2
                    F         CNTRL1
                    F         CRANK  (LEADING EDGE)
                    F         CRANK  (TRAILING EDGE)
                    F         ANTI-SYMMETRIC

                                             GEOMETRY DATA
          N          X                  Y             SWEEP ANGLE            TANGENT
          1      0.000000E+00      0.000000E+00       1-5    0.149999E+02      0.267948E+00
          2      0.207055E+01      0.000000E+00       2-6    0.149999E+02      0.267948E+00
          3      0.355099E+01      0.552510E+01
          4      0.148044E+01      0.552510E+01
          5      0.148044E+01      0.552510E+01       5-4    0.000000E+00
          6      0.355099E+01      0.552510E+01       6-3    0.000000E+00
          7      0.000000E+00      0.000000E+00
          8      0.000000E+00      0.000000E+00
          9      0.000000E+00      0.000000E+00
         10      0.000000E+00      0.000000E+00
         11      0.000000E+00      0.000000E+00
         12      0.000000E+00      0.000000E+00

      AREA OF MAIN (SEMISPAN)           AREA OF CNTRL1                  AREA OF CNTRL2
          0.114400E+02                      0.000000E+00                    0.000000E+00

                                  GRAPHIC DISPLAY OF REGIONS ON MAIN SEMISPAN
          MACH NUMBER   1.300           BOX WIDTH   0.184029          BOX LENGTH   0.152866

                                  SSSS                                                     S    MAIN
                                  SSSSSSS                                                  1    CNTRL1
                                  SSSSSSSSSS                                               2    CNTRL2
                                  SSSSSSSSSSSSS                                            .    DIAPHRAGM
                                  SSSSSSSSSSSSSSS                                          ,    WAKE
                                  SSSSSSSSSSSSSSS.
                                  SSSSSSSSSSSSSSS..
                                   SSSSSSSSSSSSSS...
                                       SSSSSSSSSS...
                                          SSSSSSS..
                                             SSSS.
                                                S

                                                        FLUTTER  SUMMARY

        POINT =    1     MACH NUMBER =  1.3000     DENSITY RATIO =  2.0606E-01     METHOD = PK

        KFREQ          1./KFREQ        VELOCITY          DAMPING          FREQUENCY             COMPLEX   EIGENVALUE
         0.0263       3.8016720E+01     1.2000000E+03    -2.1929038E-01     5.8230736E+01    -4.0116379E+01     3.6587451E+02
         0.0266       3.7556377E+01     1.3000000E+03    -2.3566487E-01     6.3856529E+01    -4.7277016E+01     4.0122241E+02
         0.0275       3.6366863E+01     1.4000000E+03    -2.5580588E-01     7.1017899E+01    -5.7072674E+01     4.4621863E+02
         0.0292       3.4202660E+01     1.5000000E+03    -2.8859755E-01     8.0905304E+01    -7.3353279E+01     5.0834305E+02
         0.0327       3.0585239E+01     1.6000000E+03    -4.1954195E-01     9.6505875E+01    -1.2719764E+02     6.0636432E+02
         0.0324       3.0884527E+01     1.7000000E+03    -7.8819412E-01     1.0154384E+02    -2.5144133E+02     6.3801880E+02

        POINT =    2     MACH NUMBER =  1.3000     DENSITY RATIO =  2.0606E-01     METHOD = PK

        KFREQ          1./KFREQ        VELOCITY          DAMPING          FREQUENCY             COMPLEX   EIGENVALUE
         0.0782       1.2782905E+01     1.2000000E+03    -9.1660082E-02     1.7317984E+02    -4.9868633E+01     1.0881211E+03
         0.0689       1.4511147E+01     1.3000000E+03    -9.5254958E-02     1.6526743E+02    -4.9456654E+01     1.0384059E+03
         0.0603       1.6595564E+01     1.4000000E+03    -9.4836451E-02     1.5562582E+02    -4.6366772E+01     9.7782593E+02
         0.0517       1.9342052E+01     1.5000000E+03    -8.1455477E-02     1.4306529E+02    -3.6610401E+01     8.9890582E+02
         0.0423       2.3650806E+01     1.6000000E+03     3.0586945E-02     1.2480145E+02     1.1992387E+01     7.8415070E+02
         0.0373       2.6796661E+01     1.7000000E+03     3.4935716E-01     1.1703448E+02     1.2844978E+02     7.3534937E+02

        POINT =    3     MACH NUMBER =  1.3000     DENSITY RATIO =  2.0606E-01     METHOD = PK

        KFREQ          1./KFREQ        VELOCITY          DAMPING          FREQUENCY             COMPLEX   EIGENVALUE
         0.1210       8.2624607E+00     1.2000000E+03    -3.2511093E-02     2.6792761E+02    -2.7365219E+01     1.6834390E+03
         0.1123       8.9064770E+00     1.3000000E+03    -3.4038611E-02     2.6926691E+02    -2.8794180E+01     1.6918540E+03
         0.1048       9.5409346E+00     1.4000000E+03    -3.5570826E-02     2.7069656E+02    -3.0250084E+01     1.7008368E+03
         0.0984       1.0165442E+01     1.5000000E+03    -3.7107173E-02     2.7221411E+02    -3.1733528E+01     1.7103717E+03
         0.0928       1.0779650E+01     1.6000000E+03    -3.8647830E-02     2.7381735E+02    -3.3245739E+01     1.7204453E+03
         0.0878       1.1383230E+01     1.7000000E+03    -4.0193569E-02     2.7550473E+02    -3.4788486E+01     1.7310474E+03
```

Low Supersonic Flutter Analysis of the 15-Degree Sweptback Wing Using ZONA51 Aerodynamics (Examples HA145FA and HA145FB)

The previous Example HA145F illustrated the Mach Box method within its limitations to an isolated wing. The ZONA51 supersonic lifting surface theory is more general in that it can analyze multiple interfering surfaces, and it is illustrated here in this variation on HA145F designated HA145FA. It is necessary to replace the CAERO3 and PAERO3 entries in HA145F by CAERO1 and PAERO1 entries. For this application the CAERO1 entry is specified with 10 equal chordwise and 10 equal spanwise divisions. The SPLINE1 entry is also modified to connect aerodynamic boxes 101 through 200 to the same 20 grid points of the structure as in HA145F. The new input data are shown in Listing 8-20. The Sorted Bulk Data entries for the modified input are shown next in Listing 8-21 followed by the flutter solution summaries for the three output flutter modes in Listing 8-22. The second flutter mode (Point 2) is the critical one. Linear interpolation between tabulated values gives a flutter speed $V_f = 1576\text{ ft/s}$ and a flutter frequency of $f_f = 132\text{ Hz}$. These may be compared to the test results, $V_f = 1280\text{ ft/s}$ and $f_f = 102\text{ Hz}$, and also to the Mach Box results of Example HA145F, $V_f = 1540\text{ ft/s}$ and $f_f = 134\text{ Hz}$.

At the end of the discussion of the Mach Box correlation in the previous section, it was noted that neglecting thickness effects in supersonic flutter analysis is unconservative, and that the correction matrix $[W_{kk}]$ (see (2-21)) might be utilized to adjust the aerodynamic center predicted by the Mach Box method. The ZONA51 supersonic lifting surface theory also neglects thickness effects so a correction factor scheme is suggested here based on Piston Theory. This variation of HA145FA is called HA145FB.

The oscillatory aerodynamic coefficients from Piston Theory have been developed by Rodden, Farkas, Malcom, and Kliszewski (1962) [Reference 47] to include modifications from the second order of Van Dyke (1952) [Reference 63] in order to extend the validity of Piston Theory to lower supersonic Mach numbers. The oscillatory coefficients are referred to the semichord, so the aerodynamic center as a fraction of the semichord measured from the leading edge is given by

$$\frac{2x_{ac}}{c} = \frac{M_{ho}}{L_{ho}} \tag{8-2}$$

$$= \frac{K_2}{K_1} \tag{8-3}$$

$$= \frac{\bar{C}_1 + 4\bar{C}_2 M I_2 + 3C_3 M^2(2I_5 + \alpha_o^2)}{\bar{C}_1 + 2\bar{C}_2 M I_1 + 3C_3 M^2(I_4 + \alpha_o^2)} \tag{8-4}$$

The coefficients $\bar{C}_1$ and $\bar{C}_2$ are discussed on the CAERO5 Bulk Data entry, the third-order coefficient is $C_3 = (\gamma + 1)/12$ from Piston Theory. The thickness integrals I_1, I_2, I_4, and I_5 are also discussed on the CAERO5 Bulk Data entry. (8-4) is conservative (that is, predicts a farther forward aerodynamic center) if the third-order effect of trim angle of attack α_o is neglected. Therefore, (8-4) will be rewritten for the purposes of the correction as

$$\frac{x_{ac}}{c} = \frac{1}{2}\frac{\bar{C}_1 + 4\bar{C}_2 M I_2 + 6 C_3 M^2 I_5}{\bar{C}_1 + 2\bar{C}_2 M I_1 + 3 C_3 M^2 I_4} \tag{8-5}$$

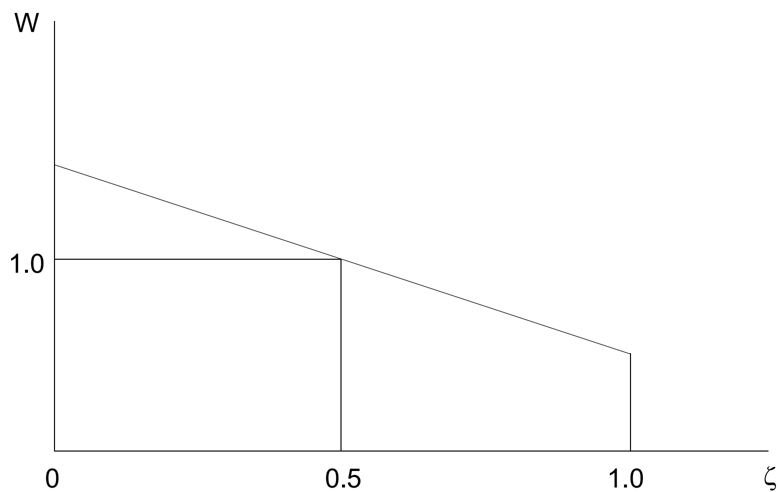

Figure 8-11 Linear Chordwise Correction Factor

Figure 8-11 shows a linear variation in the chordwise correction factor required to shift forward the theoretical uniform pressure distribution due to the angle of attack of a flat plate airfoil. The linear correction factor is

$$W = 1 + w(0.5 - \xi) \tag{8-6}$$

where ξ is measured aft from the leading edge. If the chordwise load is $l(\xi)$, the corrected lift is

$$L = \int_0^1 W l(\xi) d\xi \tag{8-7}$$

and the moment about the leading edge is

$$M_o = \int_0^1 W l(\xi)\xi d\xi \tag{8-8}$$

The aerodynamic center is located at

$$\frac{x_{ac}}{c} = \frac{M_o}{L} \tag{8-9}$$

Assume $l(\xi) = 1$, so $L = 1.0$, $M_o = 1/2 - w/12$, and the loading correction is found to be

$$w = 6 - 12\left(\frac{x_{ac}}{c}\right) \tag{8-10}$$

and the correction factor is found from (8-6).

The procedure is illustrated by modifying the above Example HA145FA. The thickness integrals can be obtained from Example HA75G (Rodden, 1987) [Reference 43].

$$I_1 = 0$$

$$I_2 = -0.008663$$

$$I_4 = 0.001568$$

$$I_5 = 0.000784$$

The airfoil coefficients are

$$\bar{C}_1 = \frac{M}{\sqrt{M^2 - \sec^2\Lambda}}$$

$$\bar{C}_2 = \frac{M^4(\gamma+1) - 4\sec^2\Lambda(M^2 - \sec^2\Lambda)}{4(M^2 - \sec^2\Lambda)^2}$$

$$C_3 = \frac{\gamma+1}{12}$$

The example wing has a leading edge sweep angle of $\Lambda = 15°$ and air has a specific heat ratio of $\gamma = 1.400$, so the following coefficients, aerodynamic center locations, and loading corrections are found:

M	$\bar{C}_1$	$\bar{C}_2$	$\bar{C}_3$	x_{ac}/c	w
1.3	1.6534	2.7502	0.2	0.4626	0.4488

The ZONA51 idealization for the example wing uses 10 equal chordwise and 10 equal spanwise divisions. The correction factors are then the same on each strip and are tabulated in Table 8-3 from (8-6).

Table 8-3 Correction Factors for the 15-Degree Sweptback Wing at Mach 1.3

ξ	W
0.05	1.2020
0.15	1.1571
0.25	1.1122
0.35	1.0673
0.45	1.0224
0.55	0.9776
0.65	0.9327
0.75	0.8878
0.85	0.8429
0.95	0.7980

Listing 8-23 shows the Input Data for HA145FB that includes the DMI input for the correction factors for the 10 strips. Listing 8-24 gives the sorted Bulk Data entries. The Flutter Summaries for the three output flutter modes are shown in Listing 8-25; interpolation between tabulated values for the critical mode gives a flutter speed $V_f = 1405 \text{ ft/s}$ and frequency $f_f = 129 \text{ Hz}$. These results are seen to compare somewhat more closely to the test results discussed above ($V_f = 1280 \text{ ft/s}$ and $f_f = 102 \text{ Hz}$).

Listing 8-20 Input Data for the 15-Degree Sweptback Wing with ZONA51 Aerodynamics

```
    N A S T R A N    E X E C U T I V E    C O N T R O L    D E C K    E C H O
ID MSC, HA145FA
$$$$$$$$ HANDBOOK FOR AEROELASTIC ANALYSIS EXAMPLE HA145FA      $$$$$$$$        $
$                                                                               $
$       MODEL DESCRIPTION       MODEL A OF NASA TN D-1824                       $
$                               HALF SPAN 15 DEGREE SWEPT WING                  $
$                               28 QUAD4 PANEL MODEL                            $
$                                                                               $
$       SOLUTION                PK-FLUTTER ANALYSIS METHOD                      $
$                               USING ZONA51 AERODYNAMICS                       $
$                               AT MACH NO. 1.3                                 $
$                                                                               $
$       OUTPUT                  PLOTS OF VIBRATION MODES AND X-Y                $
$                               PLOTS OF V-G FLUTTER DATA                       $
$                                                                               $
$$$$$$$$                                                        $$$$$$$$        $
TIME 5  $ CPU TIME IN MINUTES
SOL 145  $ FLUTTER ANALYSIS
CEND
```

```
EXAMPLE HA145FA: HALF SPAN 15-DEG SWEPT UNTAPERED WING                                                  PAGE 2
      PK-METHOD OF FLUTTER ANALYSIS, ZONA51 AERO

      0.041 IN AL PLATE W/BEVELLED LEADING AND TRAILING EDGES

                                   C A S E    C O N T R O L    D E C K    E C H O

          CARD
          COUNT
          TITLE = EXAMPLE HA145FA: HALF SPAN 15-DEG SWEPT UNTAPERED WING
          SUBT  = PK-METHOD OF FLUTTER ANALYSIS, ZONA51 AERO
          LABEL = 0.041 IN AL PLATE W/BEVELLED LEADING AND TRAILING EDGES
            ECHO    = BOTH
            SPC     = 1    $
            SDAMP   = 2000
            METHOD  = 10   $ MODIFIED GIVENS
            FMETHOD = 30   $ PK-FLUTTER METHOD
            DISP    = ALL $ PRINT VIBRATION MODES
          OUTPUT(PLOT)
            CSCALE 2.0
            PLOTTER NASTRAN
            SET 1  = QUAD4
            PTITLE = STRUCTURAL ELEMENTS
            FIND SCALE, ORIGIN 1, SET 1
            PLOT MODAL 0
          OUTPUT (XYOUT)
            CSCALE 2.0
            PLOTTER NASTRAN
            CURVELINESYMBOL = -6
            YTTITLE = DAMPING  G
            YBTITLE = FREQUENCY  F  HZ
            XTITLE  = VELOCITY  V (IN/SEC)
            XTGRID LINES = YES
            XBGRID LINES = YES
            YTGRID LINES = YES
            YBGRID LINES = YES
            UPPER TICS  = -1
            TRIGHT TICS = -1
            BRIGHT TICS = -1
            XYPLOT VG / 1(G,F) 2(G,F) 3(G,F)
          BEGIN BULK
```

Listing 8-20 Input Data for the 15-Degree Sweptback Wing with ZONA51 Aerodynamics (Continued)

```
EXAMPLE HA145FA: HALF SPAN 15-DEG SWEPT UNTAPERED WING                                                       PAGE     3

 PK-METHOD OF FLUTTER ANALYSIS, ZONA51 AERO
 0.041 IN AL PLATE W/BEVELLED LEADING AND TRAILING EDGES

                                      I N P U T   B U L K   D A T A   D E C K   E C H O

                                  .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                                   $*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
                                   $                                                                        $
                                   $        THE ANNOTATIONS IN THIS INPUT DECK ARE INTENDED TO              $
                                   $        EXPLAIN THE DATA ON THE CARD IMAGES FOR THIS                    $
                                   $        EXAMPLE WITHOUT REFERENCE TO THE VARIOUS MANUALS WHERE          $
                                   $        MORE GENERAL DESCRIPTIONS WILL BE FOUND.                        $
                                   $                                                                        $
                                   $*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
                                   $                                                                        $
                                   INCLUDE PLATE_STRUCT.DAT
                                   $                                                                        $
                                   $                 * * MASS AND INERTIA PROPERTIES * *                    $
                                   $                                                                        $
                                   $        THE MAT1 ENTRY DEFINES THE MATERIAL PROPERTIES FOR LINEAR,      $
                                   $        TEMPERATURE-INDEPENDENT, ISOTROPIC MATERIALS.  IT LISTS         $
                                   $        YOUNGS MODULUS, THE SHEAR MODULUS, POISSONS RATIO,              $
                                   $        MASS DENSITY, THERMAL EXPANSION COEFFICIENT AND STRUCTURAL      $
                                   $        ELEMENT DAMPING.                                                $
                                   $                                                                        $
                                   $       MID     E       G       NU      RHO     A       TREF    GE
                                   MAT1    1       9.2418+63.4993+6        0.097464
                                   $                                                                        $
                                   $                    * * STRUCTURAL CONSTRAINTS * *                      $
                                   $                                                                        $
                                   $        THE SPC1 ENTRY DEFINES SETS OF SINGLE-POINT CONSTRAINTS.        $
                                   $        IT LISTS THE DOF COMPONENTS TO BE CONSTRAINED AND THE GRID      $
                                   $        POINT NO.                                                       $
                                   $                                                                        $
                                   $       SID     C       G1      G2      ETC
                                   SPC1    1       12345   9
                                   SPC1    1       12345   25
                                   SPC1    1       6       1       THRU    40
                                   $                                                                        $
                                   $        THE ASET1 ENTRY DEFINES DOFS THAT THE USER DESIRES TO BE        $
                                   $        INDEPENDENT.  IT LISTS THE DOF COMPONENT NUMBERS AND THE        $
                                   $        GRID ID NO.S.                                                   $
                                   $                                                                        $
                                   $       V       ID1     THRU    ID2
                                   ASET1   3        1      THRU     8
                                   ASET1   3       10      THRU    24
                                   ASET1   3       26      THRU    40
                                   $                                                                        $
                                   $                      *  STRUCTURAL DAMPING *                           $
                                   $                                                                        $
                                   $        THE PARAMETER KDAMP DETERMINES THE MANNER OF INCLUDING          $
                                   $        STRUCTURAL DAMPING IN THE EQUATIONS OF MOTION (SEE THE          $
                                   $        HANDBOOK FOR DYNAMIC ANALYSIS, SECTION 3.2.2).  IF SET TO       $
                                   $        -1, MODAL STRUCTURAL DAMPING IS INCLUDED AS THE IMAGINARY       $
                                   $        PART OF A COMPLEX STIFFNESS MATRIX.                             $
                                   $                                                                        $
                                   $       N       V1      V2                                               $
                                   PARAM   KDAMP   +1
                                   $                                                                        $
                                   $        THE TABDMP1 ENTRY AND TABLE DEFINE MODAL DAMPING AS A           $
                                   $        TABULAR FUNCTION OF FREQUENCY.  THE DAMPING VALUES ARE          $
                                   $        LINEAR BETWEEN THE FREQUENCY AND DAMPING PAIRS AND ARE          $
                                   $        ZERO OUTSIDE THE TABULATED FREQUENCY RANGE.                     $
                                   $                                                                        $
                                   $        ID                                                              +TDP
                                   TABDMP1 2000                                                             +T2000
                                   $       F1      G1      F2      G2      ETC             ENDT
                                   +T2000  0.0     0.01    1000.0  0.01    ENDT
                                   $                                                                        $
```

Listing 8-20 Input Data for the 15-Degree Sweptback Wing with ZONA51 Aerodynamics (Continued)

```
$                      * * * AERODYNAMIC DATA * * *                    $
$                                                                      $
$                          (LB-IN-SEC SYSTEM)                          $
$                                                                      $
$        THE AERO ENTRY SPECIFIES THE AERO COORDINATE SYSTEM, THE      $
$        VELOCITY (USED FOR DATA RECOVERY), THE REFERENCE CHORD        $
$        AND FLUID DENSITY, PLUS SYMMETRY KEYS.  SYMXZ=0 INDICATES     $
$        THAT THE MODEL IS MOUNTED AS AN ISOLATED WING; SYMXY=0        $
$        INDICATES THAT THE MODEL IS MOUNTED FAR ENOUGH FROM THE       $
$        FLOOR SO THAT REFLECTION EFFECTS ARE NEGLIGIBLE.              $
$                                                                      $
$       ACSID   VELOCITY REFC   RHOREF  SYMXZ   SYMXY
AERO    0               2.07055 1.145-7 1
$                                                                      $
$        THE CAERO1 ENTRY IS USED FOR DOUBLET LATTICE AERODYNAMICS.    $
$        LISTED ARE ITS PAERO ENTRY ID AND THE COORDINATE SYSTEM       $
$        FOR LOCATING THE INBOARD AND OUTBOARD LEADING EDGE POINTS     $
$        (1 AND 4).  NSPAN AND NCHORD, OR LSPAN AND LCHORD, ARE        $
$        USED TO PARTITION THE WING INTO AERODYNAMIC PANELS.           $
$        THE FORMER FOR UNIFORMLY SPACED PANELS AND THE LATTER         $
$        FOR NON-UNIFORMLY SPACED PANELS.  IGID IS THE ID OF ITS       $
$        ASSOCIATED INTERFERENCE GROUP.  THE CONTINUATION ENTRY        $
$        DEFINES POINTS 1 AND 4, THE ROOT CHORD AND TIP CHORD.         $
$        THE BOXES FORMED BY THE GRID LINES WILL BE NUMBERED           $
$        BEGINNING WITH EID SO CHOOSE A NUMBER THAT IS UNIQUE,         $
$        AND IS GREATER THAN ALL STRUCTURAL GRID, SCALAR AND           $
$        EXTRA POINT IDS.                                              $
$                                                                      $
$       EID     PID     CP      NSPAN   NCHORD  LSPAN   LCHORD  IGID
CAERO1  101     1       0       10      10                      1       +CA101
$      ( FWD LEFT POINT  )    ROOTCHORD ( FWD RIGHT POINT  )  TIP CHORD
$       X1      Y1      Z1      X12     X4         Y4    Z4      X14
+CA101  .0      .0      .0      2.07055 1.48044 5.52510 0.0     2.07055
$                                                                      $
$        THE PAERO1 ENTRY IS REQUIRED EVEN THOUGH IT IS NON-FUNCTIONAL $
$        (BECAUSE THERE ARE NO ASSOCIATED BODIES IN THIS EXAMPLE).     $
$                                                                      $
$       PID     B1      B2      B3      B4      B5      B6
PAERO1  1
$                                                                      $
$                  * SURFACE SPLINE FIT ON THE WING *                  $
$                                                                      $
$        THE SPLINE1 ENTRY DEFINES A SURFACE SPLINE FOR INTERPO-       $
$        LATING OUT-OF-PLANE DISPLACEMENTS FROM THE STRUCTURAL         $
$        GRID POINTS ON THE SETG ENTRY TO THE REGION DEFINED BY        $
$        AERODYNAMIC BOXES 101 THRU 200 OF THE REGION ON THE           $
$        CAERO1 ENTRY.  DZ=0 SPECIFIES THAT NO SMOOTHING OF THE        $
$        SPLINE IS TO BE IMPOSED.                                      $
$                                                                      $
$       EID     CAERO   BOX1    BOX2    SETG    DZ
SPLINE1 100     101     101     200     100     0.0
$                                                                      $
$        THE SET1 ENTRY DEFINES THE SET OF STRUCTURAL GRID POINTS TO   $
$        BE USED BY THE SURFACE SPLINE FOR INTERPOLATION.              $
$                                                                      $
$       SID     G1      G2      ETC
SET1    100     2       4       6       8       9       11      13      +S1
+S1     15      18      20      22      24      25      27      29      +S2
+S2     31      34      36      38      40
$                                                                      $
```

Listing 8-20 Input Data for the 15-Degree Sweptback Wing with ZONA51 Aerodynamics (Continued)

```
$                      * * AERODYNAMIC DATABASE * *                    $
$                                                                      $
$        ALL COMBINATIONS OF MACH NUMBER AND REDUCED FREQUENCY LISTED  $
$        ON THE MKAERO1 ENTRY AND ITS CONTINUATION ENTRY WILL BE USED  $
$        TO GENERATE GENERALIZED AERO FORCE MATRICES.                  $
$                                                                      $
$       M1      M2      M3      ETC
MKAERO1 1.3                                                            +MK
$       K1      K2      K3      K4      ETC
+MK     .03     .04     .05
$                                                                      $
$                      * * VIBRATION ANALYSIS * *                      $
$                                                                      $
$        THE EIGR ENTRY SPECIFIES THE METHOD OF EXTRACTING THE EIGEN-  $
$        SOLUTIONS OF THE STRUCTURE. IN THIS CASE THE                  $
$        MODIFIED GIVENS METHOD.  THREE MODES ARE DESIRED, NORMAL-     $
$        IZED ON THE MAXIMUM DISPLACEMENTS.                            $
$                                                                      $
$       SID     METHOD  F1      F2              NO                     $
EIGR    10      MGIV                             6                     +ER
$       NORM                                                           $
+ER     MAX
$                                                                      $
$        OPPHIPA = 1 (WHEN ACCOMPANIED BY A DISPLACEMENT REQUEST IN    $
$        THE CASE CONTROL DECK), WILL PRODUCE THE VIBRATION MODE       $
$        DISPLACEMENTS IN THE OUTPUT.                                  $
$                                                                      $
PARAM   OPPHIPA 1
$                                                                      $
$                       * * FLUTTER ANALYSIS * *                       $
$                                                                      $
$        THE PARAM,LMODES,N ENTRY SPECIFIES THAT N MODES ARE TO BE     $
$        USED IN THE FLUTTER ANALYSIS.                                 $
$                                                                      $
PARAM   LMODES  4
$                                                                      $
$        THE FLUTTER ENTRY DEFINES THE METHOD OF SOLUTION, IDENTIFIES  $
$        THE FLFACT ENTRIES THAT FOLL0W, SPECIFIES THE INTERPOLATION   $
$        METHOD, THE NUMBER OF ROOTS DESIRED IN THE OUTPUT AND THE     $
$        CRITERION FOR CONVERGENCE.                                    $
$                                                                      $
$        SID    METHOD  DENS    MACH    RFRQ    IMETH   NVALUE  EPS    $
FLUTTER 30      PK      1       2       3       L       3
$                                                                      $
$        FLFACT ENTRIES ARE USED TO SPECIFY DENSITY RATIOS, MACH NOS   $
$        AND REDUCED FREQUENCIES/VELOCITIES FOR FLUTTER ANALYSES.      $
$                                                                      $
$       SID     F1      F2      F3      F4      F5      F6      F7     $
FLFACT  1       .20606                                                 DENSITY
FLFACT  2       1.3                                                    MACH NO
FLFACT  3       14400.  15600.  16800.  18000.  19200.  20400.         VELOCITY
$                                                                      $
$        THE PARAMETER VREF IS USED TO SCALE THE ANALYSIS UNITS OF     $
$        VELOCITY, HERE IN/S, TO THE UNITS DESIRED IN THE OUTPUT       $
$        FLUTTER SUMMARY TABLES, FT/S.                                 $
$                                                                      $
PARAM   VREF    12.0
$                                                                      $
ENDDATA
INPUT BULK DATA CARD COUNT =     310
```

Listing 8-21 Sorted Bulk Data for the 15-Degree Sweptback Wing with ZONA51 Aerodynamics

```
EXAMPLE HA145F_A: HALF SPAN 15-DEG SWEPT UNTAPERED WING                                                PAGE    10
 PK-METHOD OF FLUTTER ANALYSIS, ZONA51 AERO
 0.041 IN AL PLATE W/BEVELLED LEADING AND TRAILING EDGES
                                            S O R T E D   B U L K   D A T A   E C H O
             CARD
             COUNT        .  1  ..  2  ..  3  ..  4  ..  5  ..  6  ..  7  ..  8  ..  9  ..  10  .
                1-        AERO    0               2.07055 1.145-7 1
                2-        ASET1   3       1       THRU    8
                3-        ASET1   3       10      THRU    24
                4-        ASET1   3       26      THRU    40
                5-        CAERO1  101     1       0       10      10                      1       +CA101
                6-        +CA101  .0      .0      .0      2.07055 1.48044 5.52510 0.0     2.07055
                7-        CQUAD4  1       1       1       2       10      9                       +M00000
                8-        +M00000                 0.0     0.0     .041    .041
                9-        CQUAD4  2       1       2       3       11      10                      +M00001
               10-        +M00001                 0.0     0.0     .041    .041
               11-        CQUAD4  3       1       3       4       12      11                      +M00002
               12-        +M00002                 0.0     0.0     .041    .041
               13-        CQUAD4  4       1       4       5       13      12                      +M00003
               14-        +M00003                 0.0     0.0     .041    .041
               15-        CQUAD4  5       1       5       6       14      13                      +M00004
               16-        +M00004                 0.0     0.0     .041    .041
               17-        CQUAD4  6       1       6       7       15      14                      +M00005
               18-        +M00005                 0.0     0.0     .041    .041
               19-        CQUAD4  7       1       7       8       16      15                      +M00006
               20-        +M00006                 0.0     0.0     .041    .041
               21-        CQUAD4  8       1       9       10      18      17
               22-        CQUAD4  9       1       10      11      19      18
               23-        CQUAD4  10      1       11      12      20      19
               24-        CQUAD4  11      1       12      13      21      20
               25-        CQUAD4  12      1       13      14      22      21
               26-        CQUAD4  13      1       14      15      23      22
               27-        CQUAD4  14      1       15      16      24      23
               28-        CQUAD4  15      1       17      18      26      25
               29-        CQUAD4  16      1       18      19      27      26
               30-        CQUAD4  17      1       19      20      28      27
               31-        CQUAD4  18      1       20      21      29      28
               32-        CQUAD4  19      1       21      22      30      29
               33-        CQUAD4  20      1       22      23      31      30
               34-        CQUAD4  21      1       23      24      32      31
               35-        CQUAD4  22      1       25      26      34      33                      +M00007
               36-        +M00007                 .041    .041    0.0     0.0
               37-        CQUAD4  23      1       26      27      35      34                      +M00008
               38-        +M00008                 .041    .041    0.0     0.0
               39-        CQUAD4  24      1       27      28      36      35                      +M00009
               40-        +M00009                 .041    .041    0.0     0.0
               41-        CQUAD4  25      1       28      29      37      36                      +M00010
               42-        +M00010                 .041    .041    0.0     0.0
               43-        CQUAD4  26      1       29      30      38      37                      +M00011
               44-        +M00011                 .041    .041    0.0     0.0
               45-        CQUAD4  27      1       30      31      39      38                      +M00012
               46-        +M00012                 .041    .041    0.0     0.0
               47-        CQUAD4  28      1       31      32      40      39                      +M00013
               48-        +M00013                 .041    .041    0.0     0.0
               49-        EIGR    10      MGIV                            6                       +ER
               50-        +ER     MAX
               51-        FLFACT  1       .20606                                                  DENSITY
               52-        FLFACT  2       1.3                                                     MACH NO
               53-        FLFACT  3       14400.  15600.  16800.  18000.  19200.  20400.          VELOCITY
               54-        FLUTTER 30      PK      1       2       3       L       3
               55-        GRID    1               0.0     0.0     0.0
               56-        GRID    2               .211491 .7893   0.0
               57-        GRID    3               .422983 1.5786  0.0
               58-        GRID    4               .634474 2.3679  0.0
               59-        GRID    5               .845966 3.1572  0.0
               60-        GRID    6               1.05746 3.9465  0.0
               61-        GRID    7               1.26895 4.7358  0.0
               62-        GRID    8               1.48044 5.5251  0.0
               63-        GRID    9               .258819 0.0     0.0
               64-        GRID    10              .47031  .7893   0.0
               65-        GRID    11              .681802 1.5786  0.0
               66-        GRID    12              .893293 2.3679  0.0
               67-        GRID    13              1.10478 3.1572  0.0
               68-        GRID    14              1.31628 3.9465  0.0
               69-        GRID    15              1.52777 4.7358  0.0
               70-        GRID    16              1.73926 5.5251  0.0
```

Listing 8-21 Sorted Bulk Data for the 15-Degree Sweptback Wing with ZONA51 Aerodynamics (Continued)

```
  71-        GRID    17              1.03528 0.0     0.0
  72-        GRID    18              1.24677 .7893   0.0
  73-        GRID    19              1.45826 1.5786  0.0
  74-        GRID    20              1.66975 2.3679  0.0
  75-        GRID    21              1.88124 3.1572  0.0
  76-        GRID    22              2.09273 3.9465  0.0
  77-        GRID    23              2.30422 4.7358  0.0
  78-        GRID    24              2.51572 5.5251  0.0
  79-        GRID    25              1.81173 0.0     0.0
  80-        GRID    26              2.02322 .7893   0.0
  81-        GRID    27              2.23471 1.5786  0.0
  82-        GRID    28              2.44621 2.3679  0.0
  83-        GRID    29              2.6577  3.1572  0.0
  84-        GRID    30              2.86919 3.9465  0.0
  85-        GRID    31              3.08068 4.7358  0.0
  86-        GRID    32              3.29217 5.5251  0.0
  87-        GRID    33              2.07055 0.0     0.0
  88-        GRID    34              2.28204 .7893   0.0
  89-        GRID    35              2.49353 1.5786  0.0
  90-        GRID    36              2.70502 2.3679  0.0
  91-        GRID    37              2.91652 3.1572  0.0
  92-        GRID    38              3.12801 3.9465  0.0
  93-        GRID    39              3.3395  4.7358  0.0
  94-        GRID    40              3.55099 5.5251  0.0
  95-        MAT1    1       9.2418+63.4993+6        0.097464
  96-        MKAERO1 1.3                                                     +MK
  97-        +MK     .03     .04     .05
  98-        PAERO1  1
  99-        PARAM   COUPMASS1
 100-        PARAM   KDAMP   +1
 101-        PARAM   LMODES  4
 102-        PARAM   OPPHIPA 1
 103-        PARAM   VREF    12.0
 104-        PARAM   WTMASS  .0025901
 105-        PSHELL  1       1       .041    1               1
 106-        SET1    100     2       4       6       8       9       11      13      +S1
 107-        +S1     15      18      20      22      24      25      27      29      +S2
 108-        +S2     31      34      36      38      40
 109-        SPC1    1       6       1       THRU    40
 110-        SPC1    1       12345   9
 111-        SPC1    1       12345   25
 112-        SPLINE1 100     101     101     200     100     0.0
 113-        TABDMP1 2000                                                    +T2000
 114-        +T2000  0.0     0.01    1000.0  0.01    ENDT
             ENDDATA
       TOTAL COUNT=      115
```

Listing 8-22 Output for the 15-Degree Sweptback Wing with ZONA51 Aerodynamics

```
EXAMPLE HA145FA: HALF SPAN 15-DEG SWEPT UNTAPERED WING                                               PAGE    43
 PK-METHOD OF FLUTTER ANALYSIS, ZONA51 AERO

 0.041 IN AL PLATE W/BEVELLED LEADING AND TRAILING EDGES

                                                  FLUTTER  SUMMARY

  POINT =    1     MACH NUMBER =  1.3000     DENSITY RATIO =  2.0606E-01     METHOD = PK

  KFREQ          1./KFREQ        VELOCITY          DAMPING         FREQUENCY           COMPLEX   EIGENVALUE
   0.0264      3.7883450E+01    1.2000000E+03    -2.2285075E-01    5.8435585E+01    -4.0911121E+01    3.6716162E+02
   0.0267      3.7442520E+01    1.3000000E+03    -2.3879832E-01    6.4050705E+01    -4.8051292E+01    4.0244247E+02
   0.0276      3.6297466E+01    1.4000000E+03    -2.5805500E-01    7.1153679E+01    -5.7684547E+01    4.4707175E+02
   0.0292      3.4227066E+01    1.5000000E+03    -2.8823844E-01    8.0847618E+01    -7.3209763E+01    5.0798059E+02
   0.0326      3.0688646E+01    1.6000000E+03    -3.9644197E-01    9.6180687E+01    -1.1978912E+02    6.0432111E+02
   0.0328      3.0525984E+01    1.7000000E+03    -7.5888366E-01    1.0273653E+02    -2.4493452E+02    6.4551270E+02

  POINT =    2     MACH NUMBER =  1.3000     DENSITY RATIO =  2.0606E-01     METHOD = PK

  KFREQ          1./KFREQ        VELOCITY          DAMPING         FREQUENCY           COMPLEX   EIGENVALUE
   0.0788      1.2696283E+01    1.2000000E+03    -9.2844881E-02    1.7436139E+02    -5.0857868E+01    1.0955449E+03
   0.0695      1.4390484E+01    1.3000000E+03    -9.7258307E-02    1.6665317E+02    -5.0920208E+01    1.0471128E+03
   0.0609      1.6422031E+01    1.4000000E+03    -9.8186642E-02    1.5727034E+02    -4.8511993E+01    9.8815869E+02
   0.0524      1.9070755E+01    1.5000000E+03    -8.8135026E-02    1.4510052E+02    -4.0176067E+01    9.1169354E+02
   0.0431      2.3212460E+01    1.6000000E+03     1.5437534E-03    1.2715823E+02     6.1669767E-01    7.9895874E+02
   0.0377      2.6514278E+01    1.7000000E+03     3.2057297E-01    1.1828094E+02     1.1912189E+02    7.4318109E+02

  POINT =    3     MACH NUMBER =  1.3000     DENSITY RATIO =  2.0606E-01     METHOD = PK

  KFREQ          1./KFREQ        VELOCITY          DAMPING         FREQUENCY           COMPLEX   EIGENVALUE
   0.1210      8.2636967E+00    1.2000000E+03    -3.3892032E-02    2.6788754E+02    -2.8523315E+01    1.6831871E+03
   0.1123      8.9067831E+00    1.3000000E+03    -3.5415586E-02    2.6925769E+02    -2.9957973E+01    1.6917960E+03
   0.1048      9.5398874E+00    1.4000000E+03    -3.6938693E-02    2.7072629E+02    -3.1416792E+01    1.7010234E+03
   0.0984      1.0162581E+01    1.5000000E+03    -3.8461521E-02    2.7229074E+02    -3.2901009E+01    1.7108533E+03
   0.0928      1.0774477E+01    1.6000000E+03    -3.9984874E-02    2.7394882E+02    -3.4412407E+01    1.7212712E+03
   0.0879      1.1375218E+01    1.7000000E+03    -4.1509837E-02    2.7569876E+02    -3.5953049E+01    1.7322665E+03
```

Listing 8-23 Input Data for the 15-Degree Sweptback Wing with ZONA51 Aerodynamics and Thickness Correction

```
   N A S T R A N    E X E C U T I V E    C O N T R O L    D E C K    E C H O
ID MSC, HA145FB
$$$$$$$$ HANDBOOK FOR AEROELASTIC ANALYSIS EXAMPLE HA145FB      $$$$$$$$        $
$                                                                               $
$       MODEL DESCRIPTION       MODEL A OF NASA TN D-1824                       $
$                               HALF SPAN 15 DEGREE SWEPT WING                  $
$                               28 QUAD4 PANEL MODEL                            $
$                                                                               $
$       SOLUTION                PK-FLUTTER ANALYSIS METHOD                      $
$                               USING ZONA51 AERODYNAMICS                       $
$                               AT MACH NO. 1.3 AND CORRECTIONS                 $
$                                                                               $
$       OUTPUT                  PLOTS OF VIBRATION MODES AND X-Y                $
$                               PLOTS OF V-G FLUTTER DATA                       $
$                                                                               $
$$$$$$$$                                                        $$$$$$$$        $
TIME 5  $ CPU TIME IN MINUTES
SOL 145  $ FLUTTER ANALYSIS
CEND
```

```
EXAMPLE HA145FB: HALF SPAN 15-DEG SWEPT UNTAPERED WING                                                   PAGE     2
  PK-METHOD OF FLUTTER ANALYSIS, ZONA51 AERO WITH WKK
  0.041 IN AL PLATE W/BEVELLED LEADING AND TRAILING EDGES
                                     C A S E    C O N T R O L    D E C K    E C H O
             CARD
             COUNT
              1       TITLE = EXAMPLE HA145FB: HALF SPAN 15-DEG SWEPT UNTAPERED WING
              2       SUBT  = PK-METHOD OF FLUTTER ANALYSIS, ZONA51 AERO WITH WKK
              3       LABEL = 0.041 IN AL PLATE W/BEVELLED LEADING AND TRAILING EDGES
              4         ECHO    = BOTH
              5         SPC     = 1   $
              6         SDAMP   = 2000
              7         METHOD  = 10  $ MODIFIED GIVENS
              8         FMETHOD = 30  $ PK-FLUTTER METHOD
              9         DISP    = ALL $ PRINT VIBRATION MODES
             10       OUTPUT(PLOT)
             11         CSCALE 2.0
             12         PLOTTER NASTRAN
             13         SET 1   = QUAD4
             14         PTITLE = STRUCTURAL ELEMENTS
             15         FIND SCALE, ORIGIN 1, SET 1
             16         PLOT MODAL 0
             17       OUTPUT (XYOUT)
             18         CSCALE 2.0
             19         PLOTTER NASTRAN
             20         CURVELINESYMBOL = -6
             21         YTTITLE = DAMPING  G
             22         YBTITLE = FREQUENCY  F  HZ
             23         XTITLE  = VELOCITY  V (FT/SEC)
             24         XTGRID LINES = YES
             25         XBGRID LINES = YES
             26         YTGRID LINES = YES
             27         YBGRID LINES = YES
             28         UPPER TICS  = -1
             29         TRIGHT TICS = -1
             30         BRIGHT TICS = -1
             31         XYPLOT VG / 1(G,F) 2(G,F) 3(G,F)
             32       BEGIN BULK
```

Listing 8-23 Input Data for the 15-Degree Sweptback Wing with ZONA51 Aerodynamics and Thickness Correction

```
EXAMPLE HA145FB: HALF SPAN 15-DEG SWEPT UNTAPERED WING                                                                   PAGE     3
  PK-METHOD OF FLUTTER ANALYSIS, ZONA51 AERO WITH WKK
 0.041 IN AL PLATE W/BEVELLED LEADING AND TRAILING EDGES
                                               I N P U T   B U L K   D A T A   D E C K   E C H O

                                  .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .

                                  $*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
                                  $                                                                        $
                                  $        THE ANNOTATIONS IN THIS INPUT DECK ARE INTENDED TO              $
                                  $        EXPLAIN THE DATA ON THE CARD IMAGES FOR THIS                    $
                                  $        EXAMPLE WITHOUT REFERENCE TO THE VARIOUS MANUALS WHERE          $
                                  $        MORE GENERAL DESCRIPTIONS WILL BE FOUND.                        $
                                  $                                                                        $
                                  $*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
                                  $                                                                        $
                                  INCLUDE PLATE_STRUCT.DAT
                                  $
                                  $                  * * MASS AND INERTIA PROPERTIES * *                   $
                                  $                                                                        $
                                  $        THE MAT1 ENTRY DEFINES THE MATERIAL PROPERTIES FOR LINEAR,      $
                                  $        TEMPERATURE-INDEPENDENT, ISOTROPIC MATERIALS.  IT LISTS         $
                                  $        YOUNGS MODULUS, THE SHEAR MODULUS, POISSONS RATIO,              $
                                  $        MASS DENSITY, THERMAL EXPANSION COEFFICIENT AND STRUCTURAL      $
                                  $        ELEMENT DAMPING.                                                $
                                  $                                                                        $
                                  $       MID     E       G       NU      RHO     A       TREF    GE
                                  MAT1    1       9.2418+63.4993+6        0.097464
                                  $                                                                        $
                                  $                     * * STRUCTURAL CONSTRAINTS * *                     $
                                  $                                                                        $
                                  $        THE SPC1 ENTRY DEFINES SETS OF SINGLE-POINT CONSTRAINTS.        $
                                  $        IT LISTS THE DOF COMPONENTS TO BE CONSTRAINED AND THE GRID      $
                                  $        POINT NO.                                                       $
                                  $                                                                        $
                                  $       SID     C       G1      G2      ETC
                                  SPC1    1       12345   9
                                  SPC1    1       12345   25
                                  SPC1    1       6       1       THRU    40
                                  $                                                                        $
                                  $        THE ASET1 ENTRY DEFINES DOFS THAT THE USER DESIRES TO BE        $
                                  $        INDEPENDENT.  IT LISTS THE DOF COMPONENT NUMBERS AND THE        $
                                  $        GRID ID NO.S.                                                   $
                                  $                                                                        $
                                  $       V       ID1     THRU    ID2
                                  ASET1   3        1      THRU     8
                                  ASET1   3       10      THRU    24
                                  ASET1   3       26      THRU    40
                                  $                                                                        $
                                  $                       *  STRUCTURAL DAMPING *                          $
                                  $                                                                        $
                                  $        THE PARAMETER KDAMP DETERMINES THE MANNER OF INCLUDING          $
                                  $        STRUCTURAL DAMPING IN THE EQUATIONS OF MOTION (SEE THE          $
                                  $        HANDBOOK FOR DYNAMIC ANALYSIS, SECTION 3.2.2).  IF SET TO       $
                                  $        -1, MODAL STRUCTURAL DAMPING IS INCLUDED AS THE IMAGINARY       $
                                  $        PART OF A COMPLEX STIFFNESS MATRIX.                             $
                                  $                                                                        $
                                  $       N       V1      V2                                               $
                                  PARAM   KDAMP   +1
                                  $                                                                        $
                                  $        THE TABDMP1 ENTRY AND TABLE DEFINE MODAL DAMPING AS A           $
                                  $        TABULAR FUNCTION OF FREQUENCY.  THE DAMPING VALUES ARE          $
                                  $        LINEAR BETWEEN THE FREQUENCY AND DAMPING PAIRS AND ARE          $
                                  $        ZERO OUTSIDE THE TABULATED FREQUENCY RANGE.                     $
                                  $                                                                        $
                                  $       ID                                                               +TDP
                                  TABDMP1 2000                                                             +T2000
                                  $       F1      G1      F2      G2      ETC             ENDT
                                  +T2000  0.0     0.01    1000.0  0.01    ENDT
                                  $                                                                        $
```

Listing 8-23 Input Data for the 15-Degree Sweptback Wing with ZONA51 Aerodynamics and Thickness Correction

```
$                       * * * AERODYNAMIC DATA * * *                    $
$                                                                       $
$                           (LB-IN-SEC SYSTEM)                          $
$                                                                       $
$        THE AERO ENTRY SPECIFIES THE AERO COORDINATE SYSTEM, THE       $
$        VELOCITY (USED FOR DATA RECOVERY), THE REFERENCE CHORD         $
$        AND FLUID DENSITY, PLUS SYMMETRY KEYS.  SYMXZ=0 INDICATES      $
$        THAT THE MODEL IS MOUNTED AS AN ISOLATED WING; SYMXY=0         $
$        INDICATES THAT THE MODEL IS MOUNTED FAR ENOUGH FROM THE        $
$        FLOOR SO THAT REFLECTION EFFECTS ARE NEGLIGIBLE.               $
$                                                                       $
$       ACSID   VELOCITY REFC   RHOREF  SYMXZ   SYMXY
AERO    0               2.07055 1.145-7 1
$                                                                       $
$        THE CAERO1 ENTRY IS USED FOR DOUBLET LATTICE AERODYNAMICS.     $
$        LISTED ARE ITS PAERO ENTRY ID AND THE COORDINATE SYSTEM        $
$        FOR LOCATING THE INBOARD AND OUTBOARD LEADING EDGE POINTS      $
$        (1 AND 4).  NSPAN AND NCHORD, OR LSPAN AND LCHORD, ARE         $
$        USED TO PARTITION THE WING INTO AERODYNAMIC PANELS.            $
$        THE FORMER FOR UNIFORMLY SPACED PANELS AND THE LATTER          $
$        FOR NON-UNIFORMLY SPACED PANELS.  IGID IS THE ID OF ITS        $
$        ASSOCIATED INTERFERENCE GROUP.  THE CONTINUATION ENTRY         $
$        DEFINES POINTS 1 AND 4, THE ROOT CHORD AND TIP CHORD.          $
$        THE BOXES FORMED BY THE GRID LINES WILL BE NUMBERED            $
$        BEGINNING WITH EID SO CHOOSE A NUMBER THAT IS UNIQUE,          $
$        AND IS GREATER THAN ALL STRUCTURAL GRID, SCALAR AND            $
$        EXTRA POINT IDS.                                               $
$                                                                       $
$       EID     PID     CP      NSPAN   NCHORD  LSPAN   LCHORD  IGID    $
CAERO1  101     1       0       10      10                      1       +CA101
$      ( FWD LEFT POINT  )   ROOTCHORD ( FWD RIGHT POINT  )  TIP CHORD
$       X1      Y1      Z1      X12     X4      Y4      Z4      X14
+CA101  .0      .0      .0      2.07055 1.48044 5.52510 0.0     2.07055
$                                                                       $
$        THE PAERO1 ENTRY IS REQUIRED EVEN THOUGH IT IS NON-FUNCTIONAL  $
$        (BECAUSE THERE ARE NO ASSOCIATED BODIES IN THIS EXAMPLE).      $
$                                                                       $
$       PID     B1      B2      B3      B4      B5      B6
PAERO1  1
$
$         * * * CORRECTION FACTORS FOR THICKNESS * * *
$
DMI     WTFACT  0       3       1       0               200     1
DMI     WTFACT  1       1       1.2020  1.2020  1.1571  1.1571  1.1122
        1.1122  1.0673  1.06739 1.0224  1.0224  0.9776  0.9776  0.9327
        0.9327  0.8878  0.8878  0.8429  0.8429  0.7980  0.7980  1.2020
        1.2020  1.1571  1.1571  1.1122  1.1122  1.0673  1.06739 1.0224
        1.0224  0.9776  0.9776  0.9327  0.9327  0.8878  0.8878  0.8429
        0.8429  0.7980  0.7980  1.2020  1.2020  1.1571  1.1571  1.1122
        1.1122  1.0673  1.06739 1.0224  1.0224  0.9776  0.9776  0.9327
        0.9327  0.8878  0.8878  0.8429  0.8429  0.7980  0.7980  1.2020
        1.2020  1.1571  1.1571  1.1122  1.1122  1.0673  1.06739 1.0224
        1.0224  0.9776  0.9776  0.9327  0.9327  0.8878  0.8878  0.8429
        0.8429  0.7980  0.7980  1.2020  1.2020  1.1571  1.1571  1.1122
        1.1122  1.0673  1.06739 1.0224  1.0224  0.9776  0.9776  0.9327
        0.9327  0.8878  0.8878  0.8429  0.8429  0.7980  0.7980  1.2020
        1.2020  1.1571  1.1571  1.1122  1.1122  1.0673  1.06739 1.0224
        1.0224  0.9776  0.9776  0.9327  0.9327  0.8878  0.8878  0.8429
        0.8429  0.7980  0.7980  1.2020  1.2020  1.1571  1.1571  1.1122
        1.1122  1.0673  1.06739 1.0224  1.0224  0.9776  0.9776  0.9327
        0.9327  0.8878  0.8878  0.8429  0.8429  0.7980  0.7980  1.2020
        1.2020  1.1571  1.1571  1.1122  1.1122  1.0673  1.06739 1.0224
        1.0224  0.9776  0.9776  0.9327  0.9327  0.8878  0.8878  0.8429
        0.8429  0.7980  0.7980  1.2020  1.2020  1.1571  1.1571  1.1122
        1.1122  1.0673  1.06739 1.0224  1.0224  0.9776  0.9776  0.9327
        0.9327  0.8878  0.8878  0.8429  0.8429  0.7980  0.7980  1.2020
        1.2020  1.1571  1.1571  1.1122  1.1122  1.0673  1.06739 1.0224
        1.0224  0.9776  0.9776  0.9327  0.9327  0.8878  0.8878  0.8429
        0.8429  0.7980  0.7980
$                                                                       $
$                                                                       $
```

Listing 8-23 Input Data for the 15-Degree Sweptback Wing with ZONA51 Aerodynamics and Thickness Correction

```
$                  * SURFACE SPLINE FIT ON THE WING *                   $
$                                                                       $
$        THE SPLINE1 ENTRY DEFINES A SURFACE SPLINE FOR INTERPO-        $
$        LATING OUT-OF-PLANE DISPLACEMENTS FROM THE STRUCTURAL          $
$        GRID POINTS ON THE SETG ENTRY TO THE REGION DEFINED BY         $
$        AERODYNAMIC BOXES 101 THRU 200 OF THE REGION ON THE            $
$        CAERO1 ENTRY.  DZ=0 SPECIFIES THAT NO SMOOTHING OF THE         $
$        SPLINE IS TO BE IMPOSED.                                       $
$                                                                       $
$       EID     CAERO   BOX1    BOX2    SETG    DZ
SPLINE1 100     101     101     200     100     0.0
$                                                                       $
$        THE SET1 ENTRY DEFINES THE SET OF STRUCTURAL GRID POINTS TO    $
$        BE USED BY THE SURFACE SPLINE FOR INTERPOLATION.               $
$                                                                       $
$       SID     G1      G2      ETC
SET1    100     2       4       6       8       9       11      13      +S1
+S1     15      18      20      22      24      25      27      29      +S2
+S2     31      34      36      38      40
$                                                                       $
$                      * * AERODYNAMIC DATABASE * *                     $
$                                                                       $
$        ALL COMBINATIONS OF MACH NUMBER AND REDUCED FREQUENCY LISTED   $
$        ON THE MKAERO1 ENTRY AND ITS CONTINUATION ENTRY WILL BE USED   $
$        TO GENERATE GENERALIZED AERO FORCE MATRICES.                   $
$                                                                       $
$       M1      M2      M3      ETC
MKAERO1 1.3                                                             +MK
$       K1      K2      K3      K4      ETC
+MK     .03     .04     .05
$                                                                       $
$                      * * VIBRATION ANALYSIS * *                       $
$                                                                       $
$        THE EIGR ENTRY SPECIFIES THE METHOD OF EXTRACTING THE EIGEN-   $
$        SOLUTIONS OF THE STRUCTURE. IN THIS CASE THE                   $
$        MODIFIED GIVENS METHOD.  THREE MODES ARE DESIRED, NORMAL-      $
$        IZED ON THE MAXIMUM DISPLACEMENTS.                             $
$                                                                       $
$       SID     METHOD  F1      F2              NO                      $
EIGR    10      MGIV                             6                      +ER
$       NORM                                                            $
+ER     MAX
$                                                                       $
$        OPPHIPA = 1 (WHEN ACCOMPANIED BY A DISPLACEMENT REQUEST IN     $
$        THE CASE CONTROL DECK), WILL PRODUCE THE VIBRATION MODE        $
$        DISPLACEMENTS IN THE OUTPUT.                                   $
$                                                                       $
PARAM   OPPHIPA 1
$                                                                       $
$                       * * FLUTTER ANALYSIS * *                        $
$                                                                       $
$        THE PARAM,LMODES,N ENTRY SPECIFIES THAT N MODES ARE TO BE      $
$        USED IN THE FLUTTER ANALYSIS.                                  $
$                                                                       $
PARAM   LMODES  4
$                                                                       $
$        THE FLUTTER ENTRY DEFINES THE METHOD OF SOLUTION, IDENTIFIES   $
$        THE FLFACT ENTRIES THAT FOLL0W, SPECIFIES THE INTERPOLATION    $
$        METHOD, THE NUMBER OF ROOTS DESIRED IN THE OUTPUT AND THE      $
$        CRITERION FOR CONVERGENCE.                                     $
$                                                                       $
$        SID    METHOD  DENS    MACH    RFRQ    IMETH   NVALUE  EPS     $
FLUTTER 30      PK      1       2       3       L       3
$                                                                       $
$        FLFACT ENTRIES ARE USED TO SPECIFY DENSITY RATIOS, MACH NOS    $
$        AND REDUCED FREQUENCIES/VELOCITIES FOR FLUTTER ANALYSES.       $
$                                                                       $
$       SID     F1      F2      F3      F4      F5      F6      F7      $
FLFACT  1       .20606                                                  DENSITY
FLFACT  2       1.3                                                     MACH NO
FLFACT  3       14400.  15600.  16800.  18000.  19200.  20400.          VELOCITY
$                                                                       $
$        THE PARAMETER VREF IS USED TO SCALE THE ANALYSIS UNITS OF      $
$        VELOCITY, HERE IN/S, TO THE UNITS DESIRED IN THE OUTPUT        $
$        FLUTTER SUMMARY TABLES, FT/S.                                  $
$                                                                       $
PARAM   VREF    12.0
$                                                                       $
ENDDATA
```

0 INPUT BULK DATA CARD COUNT = 341

Listing 8-24 Sorted Bulk Data for the 15-Degree Sweptback Wing with ZONA51 Aerodynamics and Thickness Correction

```
EXAMPLE HA145FB: HALF SPAN 15-DEG SWEPT UNTAPERED WING                                             PAGE    11
 PK-METHOD OF FLUTTER ANALYSIS, ZONA51 AERO WITH WKK

 0.041 IN AL PLATE W/BEVELLED LEADING AND TRAILING EDGES

                                         S O R T E D   B U L K   D A T A   E C H O

             CARD
             COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                1-        AERO    0               2.07055 1.145-7 1
                2-        ASET1   3       1       THRU    8
                3-        ASET1   3       10      THRU    24
                4-        ASET1   3       26      THRU    40
                5-        CAERO1  101     1       0       10      10                      1       +CA101
                6-        +CA101  .0      .0      .0      2.07055 1.48044 5.52510 0.0     2.07055
                7-        CQUAD4  1       1       1       2       10      9                       +M00000
                8-        +M00000                 0.0     0.0     .041    .041
                9-        CQUAD4  2       1       2       3       11      10                      +M00001
               10-        +M00001                 0.0     0.0     .041    .041
               11-        CQUAD4  3       1       3       4       12      11                      +M00002
               12-        +M00002                 0.0     0.0     .041    .041
               13-        CQUAD4  4       1       4       5       13      12                      +M00003
               14-        +M00003                 0.0     0.0     .041    .041
               15-        CQUAD4  5       1       5       6       14      13                      +M00004
               16-        +M00004                 0.0     0.0     .041    .041
               17-        CQUAD4  6       1       6       7       15      14                      +M00005
               18-        +M00005                 0.0     0.0     .041    .041
               19-        CQUAD4  7       1       7       8       16      15                      +M00006
               20-        +M00006                 0.0     0.0     .041    .041
               21-        CQUAD4  8       1       9       10      18      17
               22-        CQUAD4  9       1       10      11      19      18
               23-        CQUAD4  10      1       11      12      20      19
               24-        CQUAD4  11      1       12      13      21      20
               25-        CQUAD4  12      1       13      14      22      21
               26-        CQUAD4  13      1       14      15      23      22
               27-        CQUAD4  14      1       15      16      24      23
               28-        CQUAD4  15      1       17      18      26      25
               29-        CQUAD4  16      1       18      19      27      26
               30-        CQUAD4  17      1       19      20      28      27
               31-        CQUAD4  18      1       20      21      29      28
               32-        CQUAD4  19      1       21      22      30      29
               33-        CQUAD4  20      1       22      23      31      30
               34-        CQUAD4  21      1       23      24      32      31
               35-        CQUAD4  22      1       25      26      34      33                      +M00007
               36-        +M00007                 .041    .041    0.0     0.0
               37-        CQUAD4  23      1       26      27      35      34                      +M00008
               38-        +M00008                 .041    .041    0.0     0.0
               39-        CQUAD4  24      1       27      28      36      35                      +M00009
               40-        +M00009                 .041    .041    0.0     0.0
               41-        CQUAD4  25      1       28      29      37      36                      +M00010
               42-        +M00010                 .041    .041    0.0     0.0
               43-        CQUAD4  26      1       29      30      38      37                      +M00011
               44-        +M00011                 .041    .041    0.0     0.0
               45-        CQUAD4  27      1       30      31      39      38                      +M00012
               46-        +M00012                 .041    .041    0.0     0.0
               47-        CQUAD4  28      1       31      32      40      39                      +M00013
               48-        +M00013                 .041    .041    0.0     0.0
               49-        DMI     WTFACT  0       3       1       0               200     1
               50-        DMI     WTFACT  1       1       1.2020  1.2020  1.1571  1.1571  1.1122   +000001
               51-        ++0000011.1122  1.0673  1.06739 1.0224  1.0224  0.9776  0.9776  0.9327   +000002
               52-        ++0000020.9327  0.8878  0.8878  0.8429  0.8429  0.7980  0.7980  1.2020   +000003
               53-        ++0000031.2020  1.1571  1.1571  1.1122  1.1122  1.0673  1.06739 1.0224   +000004
               54-        ++0000041.0224  0.9776  0.9776  0.9327  0.9327  0.8878  0.8878  0.8429   +000005
               55-        ++0000050.8429  0.7980  0.7980  1.2020  1.2020  1.1571  1.1571  1.1122   +000006
               56-        ++0000061.1122  1.0673  1.06739 1.0224  1.0224  0.9776  0.9776  0.9327   +000007
               57-        ++0000070.9327  0.8878  0.8878  0.8429  0.8429  0.7980  0.7980  1.2020   +000008
               58-        ++0000081.2020  1.1571  1.1571  1.1122  1.1122  1.0673  1.06739 1.0224   +000009
               59-        ++0000091.0224  0.9776  0.9776  0.9327  0.9327  0.8878  0.8878  0.8429   +000010
               60-        ++0000100.8429  0.7980  0.7980  1.2020  1.2020  1.1571  1.1571  1.1122   +000011
               61-        ++0000111.1122  1.0673  1.06739 1.0224  1.0224  0.9776  0.9776  0.9327   +000012
               62-        ++0000120.9327  0.8878  0.8878  0.8429  0.8429  0.7980  0.7980  1.2020   +000013
               63-        ++0000131.2020  1.1571  1.1571  1.1122  1.1122  1.0673  1.06739 1.0224   +000014
               64-        ++0000141.0224  0.9776  0.9776  0.9327  0.9327  0.8878  0.8878  0.8429   +000015
               65-        ++0000150.8429  0.7980  0.7980  1.2020  1.2020  1.1571  1.1571  1.1122   +000016
               66-        ++0000161.1122  1.0673  1.06739 1.0224  1.0224  0.9776  0.9776  0.9327   +000017
               67-        ++0000170.9327  0.8878  0.8878  0.8429  0.8429  0.7980  0.7980  1.2020   +000018
               68-        ++0000181.2020  1.1571  1.1571  1.1122  1.1122  1.0673  1.06739 1.0224   +000019
               69-        ++0000191.0224  0.9776  0.9776  0.9327  0.9327  0.8878  0.8878  0.8429   +000020
               70-        ++0000200.8429  0.7980  0.7980  1.2020  1.2020  1.1571  1.1571  1.1122   +000021
```

Listing 8-24 Sorted Bulk Data for the 15-Degree Sweptback Wing with ZONA51 Aerodynamics and Thickness Correction

```
  71-        ++0000211.1122  1.0673  1.06739 1.0224  1.0224  0.9776  0.9776  0.9327   +000022
  72-        ++0000220.9327  0.8878  0.8878  0.8429  0.8429  0.7980  0.7980  1.2020   +000023
  73-        ++0000231.2020  1.1571  1.1571  1.1122  1.1122  1.0673  1.06739 1.0224   +000024
  74-        ++0000241.0224  0.9776  0.9776  0.9327  0.9327  0.8878  0.8878  0.8429   +000025
  75-        ++0000250.8429  0.7980  0.7980                                           +000026
  76-        EIGR    10      MGIV                            6                       +ER
  77-        +ER     MAX
  78-        FLFACT  1       .20606                                                  DENSITY
  79-        FLFACT  2       1.3                                                     MACH NO
  80-        FLFACT  3       14400.  15600.  16800.  18000.  19200.  20400.          VELOCITY
  81-        FLUTTER 30      PK      1       2       3       L       3
  82-        GRID    1               0.0     0.0     0.0
  83-        GRID    2               .211491 .7893   0.0
  84-        GRID    3               .422983 1.5786  0.0
  85-        GRID    4               .634474 2.3679  0.0
  86-        GRID    5               .845966 3.1572  0.0
  87-        GRID    6               1.05746 3.9465  0.0
  88-        GRID    7               1.26895 4.7358  0.0
  89-        GRID    8               1.48044 5.5251  0.0
  90-        GRID    9               .258819 0.0     0.0
  91-        GRID    10              .47031  .7893   0.0
  92-        GRID    11              .681802 1.5786  0.0
  93-        GRID    12              .893293 2.3679  0.0
  94-        GRID    13              1.10478 3.1572  0.0
  95-        GRID    14              1.31628 3.9465  0.0
  96-        GRID    15              1.52777 4.7358  0.0
  97-        GRID    16              1.73926 5.5251  0.0
  98-        GRID    17              1.03528 0.0     0.0
  99-        GRID    18              1.24677 .7893   0.0
 100-        GRID    19              1.45826 1.5786  0.0
 101-        GRID    20              1.66975 2.3679  0.0
 102-        GRID    21              1.88124 3.1572  0.0
 103-        GRID    22              2.09273 3.9465  0.0
 104-        GRID    23              2.30422 4.7358  0.0
 105-        GRID    24              2.51572 5.5251  0.0
 106-        GRID    25              1.81173 0.0     0.0
 107-        GRID    26              2.02322 .7893   0.0
 108-        GRID    27              2.23471 1.5786  0.0
 109-        GRID    28              2.44621 2.3679  0.0
 110-        GRID    29              2.6577  3.1572  0.0
 111-        GRID    30              2.86919 3.9465  0.0
 112-        GRID    31              3.08068 4.7358  0.0
 113-        GRID    32              3.29217 5.5251  0.0
 114-        GRID    33              2.07055 0.0     0.0
 115-        GRID    34              2.28204 .7893   0.0
 116-        GRID    35              2.49353 1.5786  0.0
 117-        GRID    36              2.70502 2.3679  0.0
 118-        GRID    37              2.91652 3.1572  0.0
 119-        GRID    38              3.12801 3.9465  0.0
 120-        GRID    39              3.3395  4.7358  0.0
 121-        GRID    40              3.55099 5.5251  0.0
 122-        MAT1    1       9.2418+63.4993+6        0.097464
 123-        MKAERO1 1.3                                                             +MK
 124-        +MK     .03     .04     .05
 125-        PAERO1  1
 126-        PARAM   COUPMASS1
 127-        PARAM   KDAMP   +1
 128-        PARAM   LMODES  4
 129-        PARAM   OPPHIPA 1
 130-        PARAM   VREF    12.0
 131-        PARAM   WTMASS  .0025901
 132-        PSHELL  1       1       .041    1               1
 133-        SET1    100     2       4       6       8       9       11      13      +S1
 134-        +S1     15      18      20      22      24      25      27      29      +S2
 135-        +S2     31      34      36      38      40
 136-        SPC1    1       6       1       THRU    40
 137-        SPC1    1       12345   9
 138-        SPC1    1       12345   25
 139-        SPLINE1 100     101     101     200     100     0.0
 140-        TABDMP1 2000                                                            +T2000
 141-        +T2000  0.0     0.01    1000.0  0.01    ENDT
             ENDDATA
       TOTAL COUNT=       142
```

Listing 8-25 Output for the 15-Degree Sweptback Wing with ZONA51 Aerodynamics and Thickness Correction

```
EXAMPLE HA145FB: HALF SPAN 15-DEG SWEPT UNTAPERED WING                                                   PAGE    51
 PK-METHOD OF FLUTTER ANALYSIS, ZONA51 AERO WITH WKK

 0.041 IN AL PLATE W/BEVELLED LEADING AND TRAILING EDGES

                                                    FLUTTER  SUMMARY

  POINT =     1     MACH NUMBER =  1.3000     DENSITY RATIO =  2.0606E-01     METHOD = PK

  KFREQ           1./KFREQ        VELOCITY         DAMPING          FREQUENCY            COMPLEX   EIGENVALUE
   0.0287       3.4859509E+01   1.2000000E+03   -2.5494257E-01    6.3504665E+01    -5.0862518E+01    3.9901160E+02
   0.0302       3.3135532E+01   1.3000000E+03   -2.8689441E-01    7.2376068E+01    -6.5232948E+01    4.5475229E+02
   0.0336       2.9803984E+01   1.4000000E+03   -3.6845586E-01    8.6656143E+01    -1.0030780E+02    5.4447662E+02
   0.0351       2.8508036E+01   1.5000000E+03   -7.7057552E-01    9.7066551E+01    -2.3498206E+02    6.0988715E+02
   0.0321       3.1130293E+01   1.6000000E+03   -1.1467444E+00    9.4816177E+01    -3.4158511E+02    5.9574762E+02
   0.0290       3.4471218E+01   1.7000000E+03   -1.4854165E+00    9.0978317E+01    -4.2455704E+02    5.7163367E+02

  POINT =     2     MACH NUMBER =  1.3000     DENSITY RATIO =  2.0606E-01     METHOD = PK

  KFREQ           1./KFREQ        VELOCITY         DAMPING          FREQUENCY            COMPLEX   EIGENVALUE
   0.0729       1.3718625E+01   1.2000000E+03   -9.8030336E-02    1.6136760E+02    -4.9696602E+01    1.0139025E+03
   0.0619       1.6153862E+01   1.3000000E+03   -9.3216203E-02    1.4846107E+02    -4.3476433E+01    9.3280847E+02
   0.0502       1.9918922E+01   1.4000000E+03   -3.9160348E-02    1.2966055E+02    -1.5951601E+01    8.1468127E+02
   0.0415       2.4125406E+01   1.5000000E+03    3.1041557E-01    1.1469969E+02     1.1185506E+02    7.2067944E+02
   0.0378       2.6469095E+01   1.6000000E+03    6.0085303E-01    1.1151326E+02     2.1049638E+02    7.0065851E+02
   0.0348       2.8695536E+01   1.7000000E+03    8.3241701E-01    1.0928995E+02     2.8580582E+02    6.8668903E+02

  POINT =     3     MACH NUMBER =  1.3000     DENSITY RATIO =  2.0606E-01     METHOD = PK

  KFREQ           1./KFREQ        VELOCITY         DAMPING          FREQUENCY            COMPLEX   EIGENVALUE
   0.1186       8.4330111E+00   1.2000000E+03   -3.4349225E-02    2.6250903E+02    -2.8327686E+01    1.6493929E+03
   0.1098       9.1070509E+00   1.3000000E+03   -3.5831008E-02    2.6333658E+02    -2.9642860E+01    1.6545927E+03
   0.1023       9.7723389E+00   1.4000000E+03   -3.7354562E-02    2.6428659E+02    -3.1014778E+01    1.6605618E+03
   0.0959       1.0428099E+01   1.5000000E+03   -3.8922511E-02    2.6535773E+02    -3.2447594E+01    1.6672919E+03
   0.0903       1.1073617E+01   1.6000000E+03   -4.0535599E-02    2.6654843E+02    -3.3943966E+01    1.6747732E+03
   0.0854       1.1708231E+01   1.7000000E+03   -4.2193513E-02    2.6785715E+02    -3.5505760E+01    1.6829962E+03
```

High Supersonic Flutter Analysis of the 15-Degree Sweptback Wing Using Piston Theory (Example HA145G)

The flutter tests of Tuovila and McCarty (1955) [Reference 60] included an untapered magnesium plate wing with 15 degrees of sweep at a Mach number of 3.0. Since this planform has already been considered in the flutter analyses of Examples HA145E and HA145F, the same structural model (via INCLUDE PLATE_STRUCT.DAT, Listing 7-10) is used here. (See Figure 7-10) However, because the material is changed from aluminum to magnesium, the density and moduli of elasticity are different. This model was also used to demonstrate the Piston Theory by Rodden, Harder, and Bellinger (1979) [Reference 50] with a "stick" structural model. Those results will be compared to the CQUAD4 plate model used here. The PK-method of flutter analysis will be used to compare the calculated flutter speed with the test value at the same air density (altitude) and Mach number.

The version of Piston Theory implemented in MSC Nastran is based on a rigid chord with a rigid trailing edge flap without aerodynamic balance. The example wing has no control surface. It also is not rigid in the chordwise direction but can have a camber mode of vibration due to chordwise bending (cambering) of the plate elements. To obtain a mean chord line, a linear spline was used to interpolate between representative fore and aft grid points on the chord in the earlier solution [Example HA75G in Rodden (1987) [Reference 43]]. It is possible to use multiple CAERO5 entries to represent a cambering surface with certain limitations, and the present example is a reconsideration of Example HA75G using four CAERO5 entries.

The nominal properties of magnesium for the MAT1 entry include the moduli of elasticity, $E = 6.0 \times 10^6$ and $G = 2.4 \times 10^6$ psi, and a density of 0.064 lb/in^3. Using the grid point weight generator PARAM,GRDPNT,17 and the nominal density, the weight and the inertial properties with respect to GRID 17 are obtained and include a weight of 0.0262662 lb. The adjusted density to give the experimental weight of 0.0257 lb becomes 0.0626202 lb/in^3. With the adjusted density and nominal moduli, a vibration analysis yields a second mode frequency of 211.734 Hz. The second experimental frequency is 218 Hz, so adjusting the moduli by the square of the frequency ratio gives $E = 6.3604 \times 10^6$ and $G = 2.5442 \times 10^6$ psi and, consequently, a model tuned to the experimental data. The calculated first and third frequencies become 35.5 and 273.7 Hz, which compare favorably with the measured values of 37 and 270 Hz. However, the three frequencies measured on the magnesium model tested at Mach 2.0 were only 35, 205, and 234 Hz; the variations in test frequencies among nominally identical models suggests a sensitivity of the installation in the wind tunnel support fixture.

Two further details are necessary to include the structural damping, which was not measured but that is assumed to be $g = 0.01$ up to a frequency of 1000.0 rad/s. The Case Control Command SDAMP = 2000 invokes the tabulated damping TABDMP1 entry, and the damping parameter PARAM,KDAMP,+1 (the default value) selects the equivalent viscous form of the structural damping appropriate to the PK-method of flutter analysis.

The AERO entry specifies the basic coordinate system as the aerodynamic coordinate system, the reference chord of 2.0706 in., and the sea-level density; no symmetry considerations are needed since the Piston Theory is a strip theory that does not have spanwise interactions. Four CAERO5 entries divide the wing into four chordwise regions and six equal width strips. The first CAERO5 entry describes the forward beveled area of the wing, that is, the forward one-eighth chord. The second CAERO5 entry describes the forward constant thickness area of the wing between the edge of the bevel to the midchord. The third CAERO5 entry describes the aft constant thickness area of the wing between the midchord and the edge of the aft bevel. Finally, the fourth CAERO5 entry describes the aft beveled area of the wing. The four CAERO5 entries prescribe the six equal width strips, Piston Theory with the Van Dyke correction (NTHRY = 2) and a sweep correction, and the thickness integrals on AEFACT entries; the continuation entries list the coordinates of the root and tip forward edges and the chords there for each of the chordwise regions.

The thickness integrals in any analysis of a cambering surface must be input by the user; the automatic generation of the thickness integrals for a typical airfoil can no longer be used since the cambering airfoil now consists of several independent segments. The “airfoil” shape of this model consists of the beveled leading and trailing edge regions with constant thickness in between, and the thickness integrals are derived in the four chordwise regions from the general expressions:

Main Index

$$I_1 = \int_0^1 g_\xi d\xi$$

$$I_2 = \int_0^1 \xi g_\xi d\xi$$

$$I_3 = \int_0^1 \xi^2 g_\xi d\xi$$

$$I_4 = \int_0^1 g_\xi^2 d\xi$$

$$I_5 = \int_0^1 \xi g_\xi^2 d\xi$$

$$I_6 = \int_0^1 \xi^2 g_\xi^2 d\xi$$

where ξ is the dimensionless distance along the chord and g_ξ is the slope of the dimensionless semi-thickness distribution $g(\xi)$. The dimensional thickness is $2\tau c g(\xi)$ where $\tau = t/c$ is the dimensionless thickness ratio. The airfoil thickness is $t = 0.041\text{ in.}$; its chord is $c = 2.0706\text{ in.}$, and it is beveled through the first and last eighths of the chord. The thickness ratio is $\tau = 0.041/2.0706 = 0.019801$. The slope in the leading edge region is $g_\xi = (c/2)/(1/8) = 0.079204$; the slope in the trailing edge region is -0.079204, and the slope in between is zero. The first set of integrals is evaluated over the forward region and the limit $\xi = 1.0$ occurs at the one-eighth chord. The integrals for the forward region are:

$$I_1 = 0.079204$$

$$I_2 = 0.039602$$

$$I_3 = 0.026401$$

$$I_4 = 0.006273$$

$$I_5 = 0.003137$$

$$I_6 = 0.002091$$

These are entered on the AEFACT 601 entry. Because the slope of the airfoil is zero in the two intermediate chordwise regions, all of the thickness integrals are zero, and these are entered on AEFACT 602 and 603. Because the aft slope is -0.079206 in the aft beveled region, the thickness integrals are the same as in the forward region except that the first three have the opposite sign:

$$I_1 = -0.079204$$
$$I_2 = -0.039602$$
$$I_3 = -0.026401$$
$$I_4 = 0.006273$$
$$I_5 = 0.003137$$
$$I_6 = 0.002091$$

These values are entered on AEFACT 604.

The PAERO5 entry specifies a steady trim angle of attack of 0.0 radians in the NALPHA and LALPHA fields and on the AEFACT 701 entry. Since the thickness integrals are input, no thickness data (NXIS, LXIS, NTAUS, and LTAUS) are required. On the continuation entry, CAOCi = 0.0 for each strip since there is no control surface in any chordwise region.

The aerodynamic matrix database generation is prescribed on the MKAERO1 entry for the test Mach number of 3.0 and a reduced frequency range from 0.001 to 0.10, which includes the test value of 0.0399.

The surface spline is the appropriate one for a cambering surface, so four SPLINE1 entries are used, and each SPLINE1 entry corresponds to the aerodynamic elements in its corresponding CAERO5 entry. The SET1 entry for the splines lists the 20 grid points used in the Mach Box Example HA145F (p. 482).

For the vibration analysis, the Modified Givens method, MGIV, on the EIGR entry is chosen. Six modes are requested that have the largest component normalized to unity. The parameter PARAM,OPPHIPA,1, along with a DISP request in the Case Control Section, provides the vibration mode data at both the structural and aerodynamic grid points for printing and plotting.

The flutter analysis uses the lowest five of the six vibration modes as prescribed by PARAM,LMODES,5. The FLUTTER entry specifies the PK-method for the test density on FLFACT 1, the test Mach number on FLFACT 2, and the series of velocities on FLFACT 3. It also requests that three flutter eigenvalues be output from the five mode formulation. The negative velocity on FLFACT 3 requests that the flutter mode be printed at that velocity. The parameter PARAM,VREF,12.0 specifies that the Flutter Summary velocities will be divided by 12.0 in order to convert units to ft/s for comparison with the published test flutter speed. The last entry in the Bulk Data Section is ENDDATA.

Case Control Commands

The first three commands in the Case Control Section are title commands. ECHO = BOTH requests the annotated and sorted Bulk Data be printed in the output. SPC = 1 selects the constraints on the wing root deflections and on the plate element in-plane rotations. METHOD = 10 selects the eigenvalue method for the vibration analysis. SET 10 = 1 THRU 1000 and DISP = 10, along with PARAM,OPPHIPA,1 in the Bulk Data Section, request the vibration and flutter eigenvector output.

The OUTPUT(PLOT) entry identifies the plot packet for the structure plotter. The plot requests are identical to those of Example HA145E (p. 469).

The Executive Control Section begins with the problem identification, ID MSC, HA145G. TIME 5 limits the computing time to 5.0 CPU minutes, and SOL 145 requests the Structured Aerodynamic Flutter DMAP sequence. The CEND statement completes the Executive Control Section.

Output

The input data for this example are shown in Listing 8-26, followed by the sorted Bulk Data entries in Listing 8-27 and then selected output in Listing 8-28. The output data shown are discussed below.

The output begins with the weight data that were used to match the measured weight. Next are the vibration frequencies and three of the six vibration modes that were calculated, including the modes of the six aerodynamic strips (one-quarter chord deflections and rotations) in each of the four chordwise regions. The flutter solution includes the complex modal participation factors that were requested via the negative velocity at $V = 25200 \text{ in/s} = 2100 \text{ ft/s}$, the Flutter Summaries, and one of the complex flutter modes of the structural grid points.

The five mode flutter solution for the first three roots is presented in three Flutter Summaries and is preceded by the complex modal participation factors at $V = 2100 \text{ ft/s}$ and followed by the complex deflections at the structural grid points, also at $V = 2100 \text{ ft/s}$. The Flutter Summary for the second mode (Point 2) presents the critical stability data that are plotted in Figure 8-12. The calculated flutter speed is 2077 ft/s and the frequency is 148.6 Hz. The experimental flutter speed was 2030 ft/s and the frequency was 146 Hz. The results from HA75G were $V_f = 1857 \text{ ft/s}$ and $f_f = 145 \text{ Hz}$. The earlier solution of Rodden, Harder, and Bellinger (1979) [Reference 50] using a stick model and six modes obtained a flutter speed of 2170 ft/s and frequency of 168.0 Hz. The new solution accounting for camber has shown significant improvement over the earlier solutions.

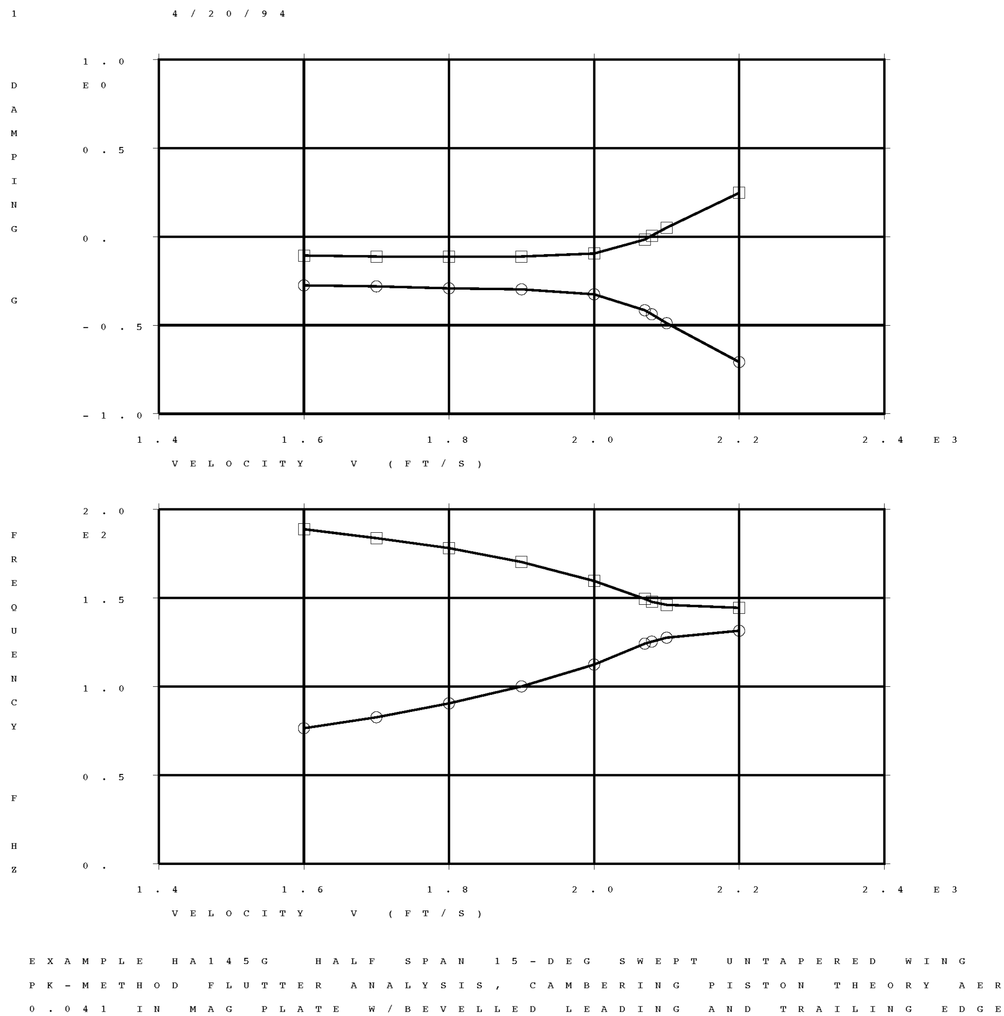

Figure 8-12 High Speed Flutter and Damping Curves for Sweptback Wing Model by Piston Theory

A difficulty that exists in MSC Nastran when using multiple CAERO5 entries to represent a cambering surface is that any sweep correction (NTHRY = 2) should be based on the sweep angle of the surface leading edge, not on the sweep angle of an aft panel. This becomes a problem for a tapered wing. This example wing has an untapered planform so the four CAERO5 panels used here all have the same leading edge sweep angle, and there is no inconsistency.

Listing 8-26 Input Data for the 15-Degree Sweptback Wing with Piston Theory Aerodynamics

```
    N A S T R A N   E X E C U T I V E   C O N T R O L   D E C K   E C H O


ID MSC, HA145G
$$$$$$$$ HANDBOOK FOR AEROELASTIC ANALYSIS EXAMPLE HA145G      $$$$$$$$
$                                                 $
$     MODEL DESCRIPTION      MODEL A OF NASA TN D-1824            $
$                     HALF SPAN 15 DEGREE SWEPT WING        $
$                     28 QUAD4 PANEL MODEL              $
$                                                 $
$     SOLUTION            PK-FLUTTER ANALYSIS METHOD            $
$                     USING PISTON THEORY METHOD            $
$                     AERODYNAMICS AT MACH NO. 3.0          $
$                                                 $
$     OUTPUT              PLOTS OF VIBRATION MODES AND X-Y      $
$                     PLOTS OF V-G FLUTTER DATA            $
$                                                 $
$$$$$$$$                                          $$$$$$$$
TIME 5 $
SOL 145  $ FLUTTER ANALYSIS
CEND



EXAMPLE HA145G: HALF SPAN 15-DEG SWEPT UNTAPERED WING                                    PAGE    3
PK-METHOD FLUTTER ANALYSIS, CAMBERING PISTON THEORY AERO

0.041 IN MAG PLATE W/BEVELLED LEADING AND TRAILING EDGES

                    C A S E   C O N T R O L   D E C K   E C H O
        CARD
        COUNT
         1      TITLE = EXAMPLE HA145G: HALF SPAN 15-DEG SWEPT UNTAPERED WING
         2      SUBT  = PK-METHOD FLUTTER ANALYSIS, CAMBERING PISTON THEORY AERO
         3      LABEL = 0.041 IN MAG PLATE W/BEVELLED LEADING AND TRAILING EDGES
         4        ECHO    = BOTH
         5        SPC     = 1   $
         6        METHOD  = 10  $ MODIFIED GIVENS
         7        FMETHOD = 30  $ PK-FLUTTER METHOD
         8        SDAMP   = 2000
         9        SET 10  = 1 THRU 1000
        10         DISP    = 10 $ GRID AND AERO BOX DISPLACEMENTS IN MODES
        11       $
        12       OUTPUT(XYOUT)
        13         CSCALE 2.0
        14         PLOTTER NASTRAN
        15         CURVELINESYMBOL = 6
        16         YTTITLE = DAMPING  G
        17         YBTITLE = FREQUENCY  F HZ
        18         XTITLE  = VELOCITY  V (FT/S)
        19         XMIN  = 1500.
        20         XMAX  = 2400.
        21         YTMIN =  -1.0
        22         YTMAX =  +1.0
        23         YBMIN =   0.
        24         YBMAX =  200.
        25         XTGRID LINES = YES
        26         XBGRID LINES = YES
        27         YTGRID LINES = YES
        28         YBGRID LINES = YES
        29         UPPER TICS  = -1
        30         TRIGHT TICS = -1
        31         BRIGHT TICS = -1
        32         XYPLOT VG / 1(G,F) 2(G,F)
        33       $
        34       BEGIN BULK
```

Listing 8-26 Input Data for the 15-Degree Sweptback Wing with Piston Theory Aerodynamics (Continued)

```
EXAMPLE HA145G: HALF SPAN 15-DEG SWEPT UNTAPERED WING                           PAGE    3
 PK-METHOD FLUTTER ANALYSIS, CAMBERING PISTON THEORY AERO
 0.041 IN MAG PLATE W/BEVELLED LEADING AND TRAILING EDGES

                    I N P U T   B U L K   D A T A   D E C K   E C H O

            . 1 .. 2 .. 3 .. 4 .. 5 .. 6 .. 7 .. 8 .. 9 .. 10 .
            $*****************************************$
            $                                        $
            $    THE ANNOTATIONS IN THIS INPUT DECK ARE INTENDED TO         $
            $    EXPLAIN THE DATA ON THE CARD IMAGES FOR THIS          $
            $    EXAMPLE WITHOUT REFERENCE TO THE VARIOUS MANUALS WHERE       $
            $    MORE GENERAL DESCRIPTIONS WILL BE FOUND.             $
            $                                        $
            $*****************************************$
            INCLUDE PLATE_STRUCT.DAT
            $                                        $
            $    THE MAT1 ENTRY DEFINES THE MATERIAL PROPERTIES FOR LINEAR,    $
            $    TEMPERATURE-INDEPENDENT, ISOTROPIC MATERIALS.  IT LISTS      $
            $    YOUNGS MODULUS, THE SHEAR MODULUS, POISSONS RATIO, DENSITY,   $
            $    THERMAL EXPANSION COEFFICIENT AND STRUCTURAL ELEMENT DAMPING.  $
            $                                        $
            $    MID    E      G      NU     RHO    A     TREF   GE
            MAT1    1     6.3604+62.5442+6      .0626202              MGNSIUM
            $                                        $
            $                                        $
            $    PARAMETER GRDPNT GENERATES THE INERTIAL MATRIX WITH RESPECT   $
            $    TO A COORDINATE SYSTEM THROUGH THE GRID POINT SPECIFIED.      $
            $                                        $
            PARAM   GRDPNT  17
            $                                        $
            $            * * STRUCTURAL CONSTRAINTS * *               $
            $                                        $
            $    THE SPC1 ENTRY DEFINES SETS OF SINGLE-POINT CONSTRAINTS.      $
            $    IT LISTS ITS ID, THE DOF COMPONENTS TO BE CONSTRAINED        $
            $    AND THE GRID POINT NO.                        $
            $                                        $
            $    SID    C      G1     G2     ETC
            SPC1    1      12345   9
            SPC1    1      12345   25
            SPC1    1      6       1      THRU    40
            $                                        $
            $    THE ASET1 ENTRY DEFINES DOFS THAT THE USER DESIRES TO BE      $
            $    IN THE ANALYSIS SET. IT LISTS THE DOF COMPONENT NUMBERS AND    $
            $    THE GRID ID NO.S.                          $
            $                                        $
            $    V      ID1    THRU   ID2
            ASET1   3       1     THRU    8
            ASET1   3      10     THRU    16
            ASET1   3      18     THRU    24
            ASET1   3      26     THRU    40
            $                                        $
            $             *  STRUCTURAL DAMPING *                 $
            $                                        $
            $    THE PARAMETER KDAMP DETERMINES THE MANNER OF INCLUDING       $
            $    STRUCTURAL DAMPING IN THE EQUATIONS OF MOTION (SEE THE       $
            $    HANDBOOK FOR DYNAMIC ANALYSIS, SECTION 3.2.2).  IF SET TO     $
            $    -1, MODAL STRUCTURAL DAMPING IS INCLUDED AS THE IMAGINARY     $
            $    PART OF A COMPLEX STIFFNESS MATRIX.                 $
            $                                        $
            $    N      V1     V2                          $
            PARAM   KDAMP   +1
            $                                        $
            $    THE TABDMP1 ENTRY AND TABLE DEFINE MODAL DAMPING AS A       $
            $    TABULAR FUNCTION OF FREQUENCY.  THE DAMPING VALUES ARE       $
            $    LINEAR BETWEEN THE FREQUENCY AND DAMPING PAIRS AND ARE       $
            $    EXTRAPOLATED OUTSIDE THE TABULATED FREQUENCY RANGE.         $
            $                                        $
            $    ID                                       +TDP
            TABDMP1 2000                                          +T2000
            $    F1     G1     F2     G2     ETC           ENDT
            +T2000  0.0     0.01    1000.0  0.01    ENDT
            $                                        $
            $            * * * AERODYNAMIC DATA * * *                $
            $                                        $
            $              (LB-IN-SEC SYSTEM)                    $
            $                                        $
            $              * * ELEMENT GEOMETRY * *                $
            $                                        $
```

Listing 8-26 Input Data for the 15-Degree Sweptback Wing with Piston Theory Aerodynamics (Continued)

```
$       THE AERO ENTRY SPECIFIES THE AERO COORDINATE SYSTEM, THE       $
$       VELOCITY (USED FOR DATA RECOVERY), THE REFERENCE CHORD         $
$       AND FLUID DENSITY, PLUS SYMMETRY KEYS.  SYMXZ=0 INDICATES      $
$       THAT THE MODEL IS MOUNTED AS AN ISOLATED WING; SYMXY=0         $
$       INDICATES THAT THE MODEL IS MOUNTED FAR ENOUGH FROM THE        $
$       FLOOR SO THAT REFLECTION EFFECTS ARE NEGLIGIBLE.               $
$                                                                      $
$      ACSID   VELOCITY REFC   RHOREF  SYMXZ   SYMXY
AERO    0               2.0706  1.145-7
$                                                                      $
$                                                                      $
$       THE CAERO5 ENTRY DEFINES PANEL ELEMENTS FOR THE PISTON         $
$       THEORY METHOD.  IT LISTS THE ID OF THE PAERO ENTRY, THE        $
$       COORDINATE SYSTEM OF POINTS 1 AND 4, THE NO. OF EQUAL          $
$       STRIPS (LSPAN WOULD SPECIFY AN AEFACT ENTRY IF UNEQUAL         $
$       STRIPS WERE SPECIFIED), AND AN AEFACT ENTRY WHERE THICKNESS    $
$       INTEGRALS WILL BE FOUND.  NTHRY SPECIFIES PISTON OR VAN        $
$       DYKES THEORY WITH OR WITHOUT SWEEP EFFECTS.  THE CONTINUA-     $
$       TION ENTRY CONTAINS THE COORDINATES OF THE ROOT AND TIP        $
$       LEADING EDGES AND THE CHORDS THERE.                            $
$                                                                      $
$      EID     PID     CP      NSPAN   LSPAN   NTHRY   NTHICK
CAERO5  101     1       0       6               2       601             +CA101
$        (INBD POINT)          X12      (OUTBD POINT)         X43
$      X1      Y1      Z1      ROOTCHORD X4    Y4      Z4      TIPCHORD
+CA101  .0      .0      .0      .258819 1.48044 5.52510 0.0     .258819
CAERO5  201     1       0       6               2       602             +CA201
+CA201  .258819 .0      .0      .776456 1.7392595.52510 0.0     .776456
CAERO5  301     1       0       6               2       603             +CA301
+CA301  1.035275.0      .0      .776456 2.5157155.52510 0.0     .776456
CAERO5  401     1       0       6               2       604             +CA401
+CA401  1.811731.0      .0      .258819 3.2921715.52510 0.0     .258819
$                                                                      $
$       THE SIX THICKNESS INTEGRALS.                                   $
$                                                                      $
AEFACT  601     0.079204 .039602 .026401 .006273 .003137 .002091
AEFACT  602     0.0     -.0     -.0     .0      .0      .0
AEFACT  603     0.0     -.0     -.0     .0      .0      .0
AEFACT  604     -.079204-.039602-.026401 .006273 .003137 .002091
$                                                                      $
$       THE PAERO5 ENTRY CONTAINS THREE PAIRS OF NUMBERS SPECIFYING    $
$       THE NUMBERS OF PARAMETERS AND THE AEFACT ENTRIES ON WHICH THEY $
$       ARE LISTED; THE PARAMETERS ARE LOCAL ANGLE OF ATTACK, LOCAL    $
$       CHORD AND LOCAL THICKNESS.  THE CONTINUATION ENTRY LISTS       $
$       TRAILING EDGE CONTROL SURFACE CHORDS IN FRACTION OF LOCAL      $
$       CHORD.                                                         $
$                                                                      $
$      PID     NALPHA  LALPHA  NXIS    LXIS    NTAUS   LTAUS
PAERO5  1       1       701                                     +PA5
$      CAOC1   CAOC2   CAOC3   CAOC4   CAOC5   CAOC6
+PA5    0.      0.      0.      0.      0.      0.
$                                                                      $
$              MACH1   ALPHA11 ALPHA12 ETC     MACH2           ETC
AEFACT  701     3.0     0.
$                                                                      $
$                  * * FLIGHT  CONDITIONS * *                          $
$                                                                      $
$       ALL COMBINATIONS OF MACH NUMBER AND REDUCED FREQUENCY LISTED   $
$       ON THE MKAERO1 ENTRY AND ITS CONTINUATION ENTRY ARE USED TO    $
$       GENERATE GENERALIZED AERODYNAMIC FORCE MATRICES.               $
$                                                                      $
$      M1      M2      M3      ETC
MKAERO1 3.0                                                     +MK
$      K1      K2      K3      ETC
+MK     .001    .02     .03     .04     .06     .10
$                                                                      $
$               * SURFACE SPLINE FIT ON THE WING *                     $
$
$       THE SPLINE1 ENTRY DEFINES A SURFACE SPLINE FOR INTERPO-        $
$       LATING OUT-OF-PLANE DISPLACEMENTS FROM THE STRUCTURAL          $
$       GRID POINTS ON THE SETG ENTRY TO THE SUB-REGION DEFINED        $
$       BY AERODYNAMIC BOXES 101 THRU 124 OF THE REGION ON THE         $
$       CAERO1 ENTRY.  DZ=0 SPECIFIES THAT NO SMOOTHING OF THE         $
$       SPLINE IS TO BE IMPOSED.                                       $
$                                                                      $
 $     EID     CAERO   BOX1    BOX2    SETG    DZ
SPLINE1 100     101     101     106     100     0.0
SPLINE1 200     201     201     206     100     0.0
SPLINE1 300     301     301     306     100     0.0
SPLINE1 400     401     401     406     100     0.0
$                                                                      $
```

Listing 8-26 Input Data for the 15-Degree Sweptback Wing with Piston Theory Aerodynamics (Continued)

```
$     THIS CORD2R ENTRY DEFINES THE SPLINE COORDINATE SYSTEM        $
$     FLAGGED BY THE SPLINE2 ENTRY.  LISTED ARE THE ORIGIN. A        $
$     POINT ALONG THE Z-AXIS, AND A POINT IN THE X-Z PLANE,          $
$     ALL IN THE RID COORDINATE SYSTEM.                              $
$                                                                    $
$     CID    RID    A1     A2     A3     B1     B2     B3     +CRD2
CORD2R  10          1.035275 0.0    0.0    1.035275 0.0    1.0     +CRD
$+CRD2  C1     C2     C3
+CRD    2.07055 -.277401 1.0
$                                                                    $
$     THE SET1 ENTRY DEFINES THE SETS OF POINTS TO BE USED BY        $
$     THE SPLINE FOR INTERPOLATION.                                  $
$                                                                    $
$     SID    G1     G2     ETC
SET1    100    2      4      6      8      9      11     13     +S1
+S1     15     18     20     22     24     25     27     29     +S2
+S2     31     34     36     38     40
$                                                                    $
$             * * VIBRATION ANALYSIS * *                             $
$                                                                    $
$     THE EIGR ENTRY SPECIFIES THE METHOD OF EXTRACTING THE EIGEN-   $
$     SOLUTIONS OF THE STRUCTURE IN A VACUUM; IN THIS CASE THE       $
$     MODIFIED GIVENS METHOD.  SIX MODES ARE REQUESTED, NORMAL-      $
$     IZED ON THE MAXIMUM DISPLACEMENTS.                             $
$                                                                    $
$     SID    METHOD  F1     F2            NO                         $
EIGR    10     MGIV                        6                  +ER
$     NORM                                                           $
+ER     MAX
$                                                                    $
$     THE PARAMETER OPPHIPA,1 PRINTS THE MODAL DISPLACEMENTS         $
$     AT THE STRUCTURAL AND AERO GRID POINTS THAT CORRESPOND         $
$     TO THE DISP AND SET REQUESTS IN THE CASE CONTROL DECK.         $
$                                                                    $
PARAM   OPPHIPA 1
$                                                                    $
$            *  * * FLUTTER ANALYSIS * * *                           $
$                                                                    $
$     THE PARAM,LMODES,N ENTRY SPECIFIES THAT N MODES ARE TO BE      $
$     USED IN THE FLUTTER ANALYSIS.                                  $
$                                                                    $
PARAM   LMODES  5
$                                                                    $
$     THE FLUTTER ENTRY DEFINES THE METHOD OF SOLUTION, IDENTIFIES   $
$     THE FLFACT ENTRIES THAT FOLL0W, SPECIFIES THE INTERPOLATION    $
$     METHOD, THE NUMBER OF ROOTS DESIRED IN THE OUTPUT AND THE      $
$     CRITERION FOR CONVERGENCE.                                     $
$                                                                    $
$     SID    METHOD  DENS   MACH   VEL    IMETH  NVALUE  EPS         $
FLUTTER 30     PK      1      2      3      L      3
$                                                                    $
$     FLFACT ENTRIES ARE USED TO SPECIFY DENSITY RATIOS, MACH NOS.   $
$     AND REDUCED FREQUENCIES/VELOCITIES FOR FLUTTER ANALYSES.       $
$                                                                    $
$     SID    F1     F2     F3     ETC
FLFACT  1      0.391                                  DENSITY
FLFACT  2      3.0                                    MACH NO
FLFACT  3      19200.  20400.  21600.  22800.  24000.  24840.  24960.  +FL3
+FL3    -25200. 26400.
$                                                                    $
$     THE PARAMETER VREF CONVERTS THE ANALYSIS UNITS OF VELOCITY     $
$     TO THE UNITS DESIRED IN THE FLUTTER SUMMARY TABLES.            $
$                                                                    $
$     N      V1     V2                                               $
PARAM   VREF    12.0
$                                                                    $
ENDDATA
INPUT BULK DATA CARD COUNT =     358
```

Listing 8-27 Sorted Bulk Data for the 15-Degree Sweptback Wing with Piston Theory Aerodynamics

```
EXAMPLE HA145G: HALF SPAN 15-DEG SWEPT UNTAPERED WING                                              PAGE    11
 PK-METHOD FLUTTER ANALYSIS, CAMBERING PISTON THEORY AERO
 0.041 IN MAG PLATE W/BEVELLED LEADING AND TRAILING EDGES

                                             S O R T E D   B U L K   D A T A   E C H O
          CARD
          COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
             1-        AEFACT  601     0.079204.039602 .026401 .006273 .003137 .002091
             2-        AEFACT  602     0.0     -.0     -.0     .0      .0      .0
             3-        AEFACT  603     0.0     -.0     -.0     .0      .0      .0
             4-        AEFACT  604     -.079204-.039602-.026401.006273 .003137 .002091
             5-        AEFACT  701     3.0     0.
             6-        AERO    0               2.0706  1.145-7
             7-        ASET1   3       1       THRU    8
             8-        ASET1   3       10      THRU    16
             9-        ASET1   3       18      THRU    24
            10-        ASET1   3       26      THRU    40
            11-        CAERO5  101     1       0       6               2       601             +CA101
            12-        +CA101  .0      .0      .0      .258819 1.48044 5.52510 0.0     .258819
            13-        CAERO5  201     1       0       6               2       602             +CA201
            14-        +CA201  .258819 .0      .0      .776456 1.7392595.52510 0.0     .776456
            15-        CAERO5  301     1       0       6               2       603             +CA301
            16-        +CA301  1.035275.0      .0      .776456 2.5157155.52510 0.0     .776456
            17-        CAERO5  401     1       0       6               2       604             +CA401
            18-        +CA401  1.811731.0      .0      .258819 3.2921715.52510 0.0     .258819
            19-        CORD2R  10              1.0352750.0     0.0     1.0352750.0     1.0     +CRD
            20-        +CRD    2.07055 -.2774011.0
            21-        CQUAD4  1       1       1       2       10      9                       +M00000
            22-        +M00000                 0.0     0.0     .041    .041
            23-        CQUAD4  2       1       2       3       11      10                      +M00001
            24-        +M00001                 0.0     0.0     .041    .041
            25-        CQUAD4  3       1       3       4       12      11                      +M00002
            26-        +M00002                 0.0     0.0     .041    .041
            27-        CQUAD4  4       1       4       5       13      12                      +M00003
            28-        +M00003                 0.0     0.0     .041    .041
            29-        CQUAD4  5       1       5       6       14      13                      +M00004
            30-        +M00004                 0.0     0.0     .041    .041
            31-        CQUAD4  6       1       6       7       15      14                      +M00005
            32-        +M00005                 0.0     0.0     .041    .041
            33-        CQUAD4  7       1       7       8       16      15                      +M00006
            34-        +M00006                 0.0     0.0     .041    .041
            35-        CQUAD4  8       1       9       10      18      17
            36-        CQUAD4  9       1       10      11      19      18
            37-        CQUAD4  10      1       11      12      20      19
            38-        CQUAD4  11      1       12      13      21      20
            39-        CQUAD4  12      1       13      14      22      21
            40-        CQUAD4  13      1       14      15      23      22
            41-        CQUAD4  14      1       15      16      24      23
            42-        CQUAD4  15      1       17      18      26      25
            43-        CQUAD4  16      1       18      19      27      26
            44-        CQUAD4  17      1       19      20      28      27
            45-        CQUAD4  18      1       20      21      29      28
            46-        CQUAD4  19      1       21      22      30      29
            47-        CQUAD4  20      1       22      23      31      30
            48-        CQUAD4  21      1       23      24      32      31
            49-        CQUAD4  22      1       25      26      34      33                      +M00007
            50-        +M00007                 .041    .041    0.0     0.0
            51-        CQUAD4  23      1       26      27      35      34                      +M00008
            52-        +M00008                 .041    .041    0.0     0.0
            53-        CQUAD4  24      1       27      28      36      35                      +M00009
            54-        +M00009                 .041    .041    0.0     0.0
            55-        CQUAD4  25      1       28      29      37      36                      +M00010
            56-        +M00010                 .041    .041    0.0     0.0
            57-        CQUAD4  26      1       29      30      38      37                      +M00011
            58-        +M00011                 .041    .041    0.0     0.0
            59-        CQUAD4  27      1       30      31      39      38                      +M00012
            60-        +M00012                 .041    .041    0.0     0.0
            61-        CQUAD4  28      1       31      32      40      39                      +M00013
            62-        +M00013                 .041    .041    0.0     0.0
            63-        EIGR    10      MGIV                            6                       +ER
            64-        +ER     MAX
            65-        FLFACT  1       0.391                                                   DENSITY
```

Listing 8-27 Sorted Bulk Data for the 15-Degree Sweptback Wing with Piston Theory Aerodynamics (Continued)

```
  66-        FLFACT  2       3.0                                                     MACH NO
  67-        FLFACT  3       19200.  20400.  21600.  22800.  24000.  24840.  24960.  +FL3
  68-        +FL3    -25200. 26400.
  69-        FLUTTER 30      PK      1       2       3       L       3
  70-        GRID    1               0.0     0.0     0.0
  71-        GRID    2               .211491 .7893   0.0
  72-        GRID    3               .422983 1.5786  0.0
  73-        GRID    4               .634474 2.3679  0.0
  74-        GRID    5               .845966 3.1572  0.0
  75-        GRID    6               1.05746 3.9465  0.0
  76-        GRID    7               1.26895 4.7358  0.0
  77-        GRID    8               1.48044 5.5251  0.0
  78-        GRID    9               .258819 0.0     0.0
  79-        GRID    10              .47031  .7893   0.0
  80-        GRID    11              .681802 1.5786  0.0
  81-        GRID    12              .893293 2.3679  0.0
  82-        GRID    13              1.10478 3.1572  0.0
  83-        GRID    14              1.31628 3.9465  0.0
  84-        GRID    15              1.52777 4.7358  0.0
  85-        GRID    16              1.73926 5.5251  0.0
  86-        GRID    17              1.03528 0.0     0.0
  87-        GRID    18              1.24677 .7893   0.0
  88-        GRID    19              1.45826 1.5786  0.0
  89-        GRID    20              1.66975 2.3679  0.0
  90-        GRID    21              1.88124 3.1572  0.0
  91-        GRID    22              2.09273 3.9465  0.0
  92-        GRID    23              2.30422 4.7358  0.0
  93-        GRID    24              2.51572 5.5251  0.0
  94-        GRID    25              1.81173 0.0     0.0
  95-        GRID    26              2.02322 .7893   0.0
  96-        GRID    27              2.23471 1.5786  0.0
  97-        GRID    28              2.44621 2.3679  0.0
  98-        GRID    29              2.6577  3.1572  0.0
  99-        GRID    30              2.86919 3.9465  0.0
 100-        GRID    31              3.08068 4.7358  0.0
 101-        GRID    32              3.29217 5.5251  0.0
 102-        GRID    33              2.07055 0.0     0.0
 103-        GRID    34              2.28204 .7893   0.0
 104-        GRID    35              2.49353 1.5786  0.0
 105-        GRID    36              2.70502 2.3679  0.0
 106-        GRID    37              2.91652 3.1572  0.0
 107-        GRID    38              3.12801 3.9465  0.0
 108-        GRID    39              3.3395  4.7358  0.0
 109-        GRID    40              3.55099 5.5251  0.0
 110-        MAT1    1       6.3604+62.5442+6        .0626202                        MGNSIUM
 111-        MKAERO1 3.0                                                             +MK
 112-        +MK     .001    .02     .03     .04     .06     .10
 113-        PAERO5  1       1       701                                             +PA5
 114-        +PA5    0.      0.      0.      0.      0.      0.
 115-        PARAM   COUPMASS1
 116-        PARAM   GRDPNT  17
 117-        PARAM   KDAMP   +1
 118-        PARAM   LMODES  5
 119-        PARAM   OPPHIPA 1
 120-        PARAM   VREF    12.0
 121-        PARAM   WTMASS  .0025901
 122-        PSHELL  1       1       .041    1               1
 123-        SET1    100     2       4       6       8       9       11      13      +S1
 124-        +S1     15      18      20      22      24      25      27      29      +S2
 125-        +S2     31      34      36      38      40
 126-        SPC1    1       6       1       THRU    40
 127-        SPC1    1       12345   9
 128-        SPC1    1       12345   25
 129-        SPLINE1 100     101     101     106     100     0.0
 130-        SPLINE1 200     201     201     206     100     0.0
 131-        SPLINE1 300     301     301     306     100     0.0
 132-        SPLINE1 400     401     401     406     100     0.0
 133-        TABDMP1 2000                                                            +T2000
 134-        +T2000  0.0     0.01    1000.0  0.01    ENDT
             ENDDATA
       TOTAL COUNT=       135
```

Listing 8-28 Output for the 15-Degree Sweptback Wing with Piston Theory Aerodynamics

```
 EXAMPLE HA145G: HALF SPAN 15-DEG SWEPT UNTAPERED WING                                                   PAGE    15
  PK-METHOD FLUTTER ANALYSIS, CAMBERING PISTON THEORY AERO
  0.041 IN MAG PLATE W/BEVELLED LEADING AND TRAILING EDGES

                      O U T P U T   F R O M   G R I D   P O I N T   W E I G H T   G E N E R A T O R
                                               REFERENCE POINT =       17
                                                        M O
                  *  2.569994E-02 -6.723324E-21  0.000000E+00  0.000000E+00  0.000000E+00 -7.099739E-02 *
                  * -6.723324E-21  2.569994E-02  0.000000E+00  0.000000E+00  0.000000E+00  1.902349E-02 *
                  *  0.000000E+00  0.000000E+00  2.569994E-02  7.099739E-02 -1.902349E-02  0.000000E+00 *
                  *  0.000000E+00  0.000000E+00  7.099739E-02  2.615118E-01 -7.007129E-02  0.000000E+00 *
                  *  0.000000E+00  0.000000E+00 -1.902349E-02 -7.007129E-02  2.594858E-02  0.000000E+00 *
                  * -7.099739E-02  1.902349E-02  0.000000E+00  0.000000E+00  0.000000E+00  2.874604E-01 *
                                                         S
                                    *  1.000000E+00  0.000000E+00  0.000000E+00 *
                                    *  0.000000E+00  1.000000E+00  0.000000E+00 *
                                    *  0.000000E+00  0.000000E+00  1.000000E+00 *
                         DIRECTION
                    MASS AXIS SYSTEM (S)     MASS              X-C.G.        Y-C.G.        Z-C.G.
                            X            2.569994E-02      0.000000E+00  2.762550E+00  0.000000E+00
                            Y            2.569994E-02      7.402154E-01  0.000000E+00  0.000000E+00
                            Z            2.569994E-02      7.402154E-01  2.762550E+00  0.000000E+00
                                                        I(S)
                                    *  6.537795E-02  1.751793E-02  0.000000E+00 *
                                    *  1.751793E-02  1.186710E-02  0.000000E+00 *
                                    *  0.000000E+00  0.000000E+00  7.724505E-02 *
                                                        I(Q)
                                    *  7.060268E-02                             *
                                    *                6.642361E-03               *
                                    *                              7.724505E-02 *
                                                         Q
                                    *  9.582864E-01  2.858095E-01  0.000000E+00 *
                                    * -2.858095E-01  9.582864E-01  0.000000E+00 *
                                    *  0.000000E+00  0.000000E+00  1.000000E+00 *

                                     R E A L   E I G E N V A L U E S
   MODE    EXTRACTION      EIGENVALUE            RADIANS             CYCLES            GENERALIZED         GENERALIZED
    NO.       ORDER                                                                       MASS              STIFFNESS
        1         1        4.966088E+04        2.228472E+02        3.546724E+01        1.597554E-05        7.933596E-01
        2         2        1.876190E+06        1.369741E+03        2.180010E+02        6.074554E-06        1.139702E+01
        3         3        2.956955E+06        1.719580E+03        2.736796E+02        5.465819E-06        1.616218E+01
        4         4        1.694829E+07        4.116830E+03        6.552139E+02        5.314034E-06        9.006378E+01
        5         5        2.949705E+07        5.431119E+03        8.643893E+02        5.243518E-06        1.546683E+02
        6         6        7.178733E+07        8.472740E+03        1.348478E+03        3.104154E-06        2.228389E+02
        7         7        1.101135E+08        1.049350E+04        1.670092E+03        0.0                 0.0
        8         8        2.209181E+08        1.486331E+04        2.365570E+03        0.0                 0.0
        9         9        3.014644E+08        1.736273E+04        2.763365E+03        0.0                 0.0
       10        10        3.820511E+08        1.954613E+04        3.110863E+03        0.0                 0.0

      EIGENVALUE =  4.966088E+04
         CYCLES =  3.546724E+01         R E A L   E I G E N V E C T O R   N O .          1

   POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
          1      G      0.0            0.0           -3.177641E-03   5.710699E-02  -2.225847E-02   0.0
          2      G      0.0            0.0            3.466399E-02   2.827334E-02  -1.574365E-02   0.0
          3      G      0.0            0.0            1.208369E-01   1.687295E-01  -3.860027E-02   0.0
          4      G      0.0            0.0            2.424595E-01   1.223329E-01  -2.303771E-02   0.0
          5      G      0.0            0.0            3.901408E-01   2.282930E-01  -4.816557E-02   0.0
          6      G      0.0            0.0            5.602161E-01   1.802223E-01  -3.166129E-02   0.0
          7      G      0.0            0.0            7.362689E-01   2.426241E-01  -4.697696E-02   0.0
          8      G      0.0            0.0            9.192188E-01   1.988754E-01  -3.358189E-02   0.0
          9      G      0.0            0.0            0.0            0.0            0.0            0.0
         10      G      0.0            0.0            4.019029E-02   9.116539E-02  -3.023629E-02   0.0
         11      G      0.0            0.0            1.287552E-01   1.183675E-01  -1.831846E-02   0.0
         12      G      0.0            0.0            2.497337E-01   1.714814E-01  -3.489073E-02   0.0
         13      G      0.0            0.0            4.012302E-01   1.916025E-01  -3.536316E-02   0.0
         14      G      0.0            0.0            5.693870E-01   2.126201E-01  -3.980973E-02   0.0
         15      G      0.0            0.0            7.475079E-01   2.164140E-01  -3.917040E-02   0.0
         16      G      0.0            0.0            9.288043E-01   2.211759E-01  -4.038252E-02   0.0
         17      G      0.0            0.0           -3.139184E-04   6.098017E-02  -6.990873E-04   0.0
         18      G      0.0            0.0            5.307267E-02   7.231662E-02  -2.554121E-03   0.0
         19      G      0.0            0.0            1.423508E-01   1.461928E-01  -1.677333E-02   0.0
         20      G      0.0            0.0            2.734013E-01   1.725224E-01  -2.565950E-02   0.0
         21      G      0.0            0.0            4.279933E-01   2.013863E-01  -3.327638E-02   0.0
         22      G      0.0            0.0            5.991349E-01   2.120074E-01  -3.647467E-02   0.0
         23      G      0.0            0.0            7.779750E-01   2.198114E-01  -3.903528E-02   0.0
         24      G      0.0            0.0            9.598176E-01   2.195428E-01  -3.923723E-02   0.0
         25      G      0.0            0.0            0.0            0.0            0.0            0.0
         26      G      0.0            0.0            4.735721E-02   1.203464E-01   1.591588E-02   0.0
         27      G      0.0            0.0            1.539442E-01   1.485789E-01  -1.306415E-02   0.0
         28      G      0.0            0.0            2.916331E-01   1.886990E-01  -2.129181E-02   0.0
         29      G      0.0            0.0            4.529409E-01   2.041422E-01  -3.071789E-02   0.0
         30      G      0.0            0.0            6.273171E-01   2.181408E-01  -3.591881E-02   0.0
         31      G      0.0            0.0            8.079913E-01   2.187324E-01  -3.807590E-02   0.0
         32      G      0.0            0.0            9.904229E-01   2.223233E-01  -3.940554E-02   0.0
         33      G      0.0            0.0           -3.292926E-03   3.037128E-02   1.764832E-02   0.0
```

Listing 8-28 Output for the 15-Degree Sweptback Wing with Piston Theory Aerodynamics (Continued)

```
         34      G      0.0           0.0           4.410950E-02   1.026832E-01   1.694509E-02   0.0
         35      G      0.0           0.0           1.569097E-01   1.761944E-01  -1.333694E-02   0.0
         36      G      0.0           0.0           2.970206E-01   1.706534E-01  -1.712837E-02   0.0
         37      G      0.0           0.0           4.611472E-01   2.267395E-01  -3.401155E-02   0.0
         38      G      0.0           0.0           6.362092E-01   1.984645E-01  -3.138098E-02   0.0
         39      G      0.0           0.0           8.184620E-01   2.411798E-01  -4.306755E-02   0.0
         40      G      0.0           0.0           1.000000E+00   1.976597E-01  -3.439136E-02   0.0
        101      G      0.0           0.0           1.783676E-02   0.0           -1.343707E-02   0.0
        102      G      0.0           0.0           9.879901E-02   0.0           -1.880716E-02   0.0
        103      G      0.0           0.0           2.328612E-01   0.0           -2.450174E-02   0.0
        104      G      0.0           0.0           4.083946E-01   0.0           -3.175720E-02   0.0
        105      G      0.0           0.0           6.061424E-01   0.0           -3.663930E-02   0.0
        106      G      0.0           0.0           8.159464E-01   0.0           -4.059823E-02   0.0
        201      G      0.0           0.0           2.388476E-02   0.0           -1.547890E-02   0.0
        202      G      0.0           0.0           1.066445E-01   0.0           -1.923210E-02   0.0
        203      G      0.0           0.0           2.439832E-01   0.0           -3.079459E-02   0.0
        204      G      0.0           0.0           4.213656E-01   0.0           -3.445108E-02   0.0
        205      G      0.0           0.0           6.208205E-01   0.0           -3.873397E-02   0.0
        206      G      0.0           0.0           8.315884E-01   0.0           -3.993377E-02   0.0
        301      G      0.0           0.0           3.023514E-02   0.0            1.538259E-03   0.0
        302      G      0.0           0.0           1.174660E-01   0.0           -8.564179E-03   0.0
        303      G      0.0           0.0           2.661315E-01   0.0           -2.238087E-02   0.0
        304      G      0.0           0.0           4.478103E-01   0.0           -3.307833E-02   0.0
        305      G      0.0           0.0           6.505368E-01   0.0           -3.650501E-02   0.0
        306      G      0.0           0.0           8.620739E-01   0.0           -3.886171E-02   0.0
        401      G      0.0           0.0           2.255161E-02   0.0            1.874720E-02   0.0
        402      G      0.0           0.0           1.231855E-01   0.0           -1.207933E-02   0.0
        403      G      0.0           0.0           2.796980E-01   0.0           -2.235178E-02   0.0
        404      G      0.0           0.0           4.692842E-01   0.0           -3.322077E-02   0.0
        405      G      0.0           0.0           6.739140E-01   0.0           -3.669397E-02   0.0
        406      G      0.0           0.0           8.872889E-01   0.0           -3.880873E-02   0.0

      EIGENVALUE =  1.876190E+06
          CYCLES =  2.180010E+02         R E A L   E I G E N V E C T O R   N O .          2

      POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
          1      G      0.0           0.0           1.076519E-02  -2.433207E-01   8.325648E-02   0.0
          2      G      0.0           0.0          -1.455797E-01  -9.741305E-02  -1.021172E-02   0.0
          3      G      0.0           0.0          -4.042479E-01  -5.123186E-01  -4.539555E-02   0.0
          4      G      0.0           0.0          -6.051180E-01  -5.583264E-02  -2.652566E-01   0.0
          5      G      0.0           0.0          -6.545121E-01  -1.959130E-01  -2.932936E-01   0.0
          6      G      0.0           0.0          -5.606913E-01   2.297285E-01  -4.505970E-01   0.0
          7      G      0.0           0.0          -3.175942E-01   1.411230E-01  -4.398463E-01   0.0
          8      G      0.0           0.0          -1.491527E-02   3.639295E-01  -5.100251E-01   0.0
          9      G      0.0           0.0           0.0            0.0            0.0           0.0
         10      G      0.0           0.0          -1.483781E-01  -3.298120E-01   4.441432E-02   0.0
         11      G      0.0           0.0          -3.850683E-01  -2.655696E-01  -1.228902E-01   0.0
         12      G      0.0           0.0          -5.425583E-01  -2.060066E-01  -2.132788E-01   0.0
         13      G      0.0           0.0          -5.742006E-01  -1.660852E-02  -3.345524E-01   0.0
         14      G      0.0           0.0          -4.483187E-01   1.292873E-01  -4.122958E-01   0.0
         15      G      0.0           0.0          -2.003406E-01   2.525528E-01  -4.655613E-01   0.0
         16      G      0.0           0.0           1.140091E-01   2.822633E-01  -4.841054E-01   0.0
         17      G      0.0           0.0          -9.321876E-04  -1.995024E-01  -5.667394E-03   0.0
         18      G      0.0           0.0          -1.469279E-01  -1.640017E-01  -5.789461E-02   0.0
         19      G      0.0           0.0          -2.871523E-01  -2.196950E-01  -1.335604E-01   0.0
         20      G      0.0           0.0          -3.702640E-01  -7.673440E-02  -2.329681E-01   0.0
         21      G      0.0           0.0          -3.166552E-01   6.370363E-02  -3.284229E-01   0.0
         22      G      0.0           0.0          -1.281732E-01   2.074918E-01  -4.103427E-01   0.0
         23      G      0.0           0.0           1.599456E-01   2.773446E-01  -4.594568E-01   0.0
         24      G      0.0           0.0           4.924163E-01   3.044380E-01  -4.869040E-01   0.0
         25      G      0.0           0.0           0.0            0.0            0.0           0.0
         26      G      0.0           0.0          -7.832745E-02  -2.032576E-01  -1.179812E-01   0.0
         27      G      0.0           0.0          -1.809497E-01  -1.080278E-01  -1.410731E-01   0.0
         28      G      0.0           0.0          -1.867020E-01   1.950497E-03  -2.388912E-01   0.0
         29      G      0.0           0.0          -6.006376E-02   1.645762E-01  -3.305187E-01   0.0
         30      G      0.0           0.0           1.926582E-01   2.657362E-01  -4.128444E-01   0.0
         31      G      0.0           0.0           5.203841E-01   3.153380E-01  -4.654136E-01   0.0
         32      G      0.0           0.0           8.721126E-01   3.133633E-01  -4.870962E-01   0.0
         33      G      0.0           0.0           9.889715E-03  -5.189328E-02  -5.428960E-02   0.0
         34      G      0.0           0.0          -5.051656E-02  -1.437815E-01  -1.161583E-01   0.0
         35      G      0.0           0.0          -1.437313E-01  -1.364077E-01  -1.389733E-01   0.0
         36      G      0.0           0.0          -1.249291E-01   7.692270E-02  -2.439464E-01   0.0
         37      G      0.0           0.0           2.522993E-02   1.456973E-01  -3.216818E-01   0.0
         38      G      0.0           0.0           3.011479E-01   3.298752E-01  -4.239694E-01   0.0
         39      G      0.0           0.0           6.403315E-01   2.736300E-01  -4.567904E-01   0.0
         40      G      0.0           0.0           1.000000E+00   3.707772E-01  -4.984170E-01   0.0
        101      G      0.0           0.0          -7.455474E-02   0.0           -6.397898E-02   0.0
        102      G      0.0           0.0          -3.329415E-01   0.0           -4.646284E-02   0.0
        103      G      0.0           0.0          -5.840117E-01   0.0           -1.627028E-01   0.0
        104      G      0.0           0.0          -6.246455E-01   0.0           -2.632753E-01   0.0
        105      G      0.0           0.0          -4.857388E-01   0.0           -3.827342E-01   0.0
        106      G      0.0           0.0          -1.622539E-01   0.0           -4.416946E-01   0.0
        201      G      0.0           0.0          -6.739552E-02   0.0            1.568056E-02   0.0
        202      G      0.0           0.0          -3.139974E-01   0.0           -5.877433E-02   0.0
        203      G      0.0           0.0          -5.065786E-01   0.0           -2.246159E-01   0.0
        204      G      0.0           0.0          -5.109797E-01   0.0           -3.176940E-01   0.0
        205      G      0.0           0.0          -3.235691E-01   0.0           -4.413960E-01   0.0
        206      G      0.0           0.0           1.586512E-02   0.0           -4.726967E-01   0.0
```

Listing 8-28 Output for the 15-Degree Sweptback Wing with Piston Theory Aerodynamics (Continued)

```
        301     G      0.0           0.0           -8.202633E-02  0.0          -8.588545E-03  0.0
        302     G      0.0           0.0           -2.446632E-01  0.0          -1.200168E-01  0.0
        303     G      0.0           0.0           -3.266103E-01  0.0          -2.111200E-01  0.0
        304     G      0.0           0.0           -2.480691E-01  0.0          -3.452822E-01  0.0
        305     G      0.0           0.0            2.038978E-02  0.0          -4.266148E-01  0.0
        306     G      0.0           0.0            3.916357E-01  0.0          -4.867139E-01  0.0
        401     G      0.0           0.0           -4.396769E-02  0.0          -1.116502E-01  0.0
        402     G      0.0           0.0           -1.499702E-01  0.0          -1.774662E-01  0.0
        403     G      0.0           0.0           -1.826435E-01  0.0          -2.506159E-01  0.0
        404     G      0.0           0.0           -1.877663E-02  0.0          -3.722009E-01  0.0
        405     G      0.0           0.0            2.958279E-01  0.0          -4.317957E-01  0.0
        406     G      0.0           0.0            7.044181E-01  0.0          -4.759348E-01  0.0

   EIGENVALUE =  2.956955E+06
       CYCLES =  2.736796E+02        R E A L   E I G E N V E C T O R   N O .         3

   POINT ID.   TYPE          T1            T2             T3             R1             R2             R3
          1     G      0.0           0.0            1.848864E-03   2.670977E-02  -2.156844E-03  0.0
          2     G      0.0           0.0            2.956194E-02   5.589033E-02   5.979180E-02  0.0
          3     G      0.0           0.0            8.557376E-02   1.325503E-01   1.615312E-01  0.0
          4     G      0.0           0.0            1.687198E-01   1.826797E-01   3.067155E-01  0.0
          5     G      0.0           0.0            2.985356E-01   3.099898E-01   4.122333E-01  0.0
          6     G      0.0           0.0            5.053338E-01   4.263177E-01   5.094689E-01  0.0
          7     G      0.0           0.0            7.534627E-01   4.660743E-01   5.890397E-01  0.0
          8     G      0.0           0.0            1.000000E+00   4.713722E-01   6.281542E-01  0.0
          9     G      0.0           0.0            0.0            0.0            0.0            0.0
         10     G      0.0           0.0            1.174052E-02   5.608930E-02   6.934599E-02  0.0
         11     G      0.0           0.0            4.094337E-02   9.363273E-02   1.812581E-01  0.0
         12     G      0.0           0.0            8.624984E-02   1.623567E-01   3.327654E-01  0.0
         13     G      0.0           0.0            1.894967E-01   2.984429E-01   4.335784E-01  0.0
         14     G      0.0           0.0            3.714224E-01   4.069353E-01   5.297652E-01  0.0
         15     G      0.0           0.0            6.004590E-01   4.597443E-01   5.964572E-01  0.0
         16     G      0.0           0.0            8.368752E-01   4.626641E-01   6.355969E-01  0.0
         17     G      0.0           0.0           -3.193164E-04  -3.943646E-02   8.194263E-03  0.0
         18     G      0.0           0.0           -5.006811E-02  -4.277097E-02   9.249041E-02  0.0
         19     G      0.0           0.0           -1.350967E-01  -5.758484E-02   2.725917E-01  0.0
         20     G      0.0           0.0           -2.014132E-01   8.103919E-02   4.064467E-01  0.0
         21     G      0.0           0.0           -1.781411E-01   2.241181E-01   5.116053E-01  0.0
         22     G      0.0           0.0           -6.092090E-02   3.570502E-01   5.819532E-01  0.0
         23     G      0.0           0.0            1.242390E-01   4.246789E-01   6.283526E-01  0.0
         24     G      0.0           0.0            3.359585E-01   4.491850E-01   6.523202E-01  0.0
         25     G      0.0           0.0            0.0            0.0            0.0            0.0
         26     G      0.0           0.0           -1.425986E-01  -2.840995E-01   1.535193E-01  0.0
         27     G      0.0           0.0           -3.830405E-01  -1.612982E-01   3.663884E-01  0.0
         28     G      0.0           0.0           -5.516362E-01  -1.735601E-02   4.943498E-01  0.0
         29     G      0.0           0.0           -6.036602E-01   1.796153E-01   5.819765E-01  0.0
         30     G      0.0           0.0           -5.328335E-01   3.202280E-01   6.310563E-01  0.0
         31     G      0.0           0.0           -3.744593E-01   4.156158E-01   6.532360E-01  0.0
         32     G      0.0           0.0           -1.771789E-01   4.325322E-01   6.660703E-01  0.0
         33     G      0.0           0.0           -5.231076E-03  -1.271440E-01   1.287095E-02  0.0
         34     G      0.0           0.0           -1.895507E-01  -2.453643E-01   1.696592E-01  0.0
         35     G      0.0           0.0           -4.825777E-01  -2.661881E-01   4.065451E-01  0.0
         36     G      0.0           0.0           -6.835402E-01   3.975718E-02   5.102635E-01  0.0
         37     G      0.0           0.0           -7.583392E-01   1.066423E-01   6.161198E-01  0.0
         38     G      0.0           0.0           -6.965958E-01   3.873594E-01   6.297446E-01  0.0
         39     G      0.0           0.0           -5.463345E-01   3.421911E-01   6.755947E-01  0.0
         40     G      0.0           0.0           -3.476769E-01   5.126567E-01   6.508620E-01  0.0
        101     G      0.0           0.0            1.408943E-02   0.0            1.305940E-01  0.0
        102     G      0.0           0.0            6.573562E-02   0.0            1.904218E-01  0.0
        103     G      0.0           0.0            1.402939E-01   0.0            3.222590E-01  0.0
        104     G      0.0           0.0            2.880635E-01   0.0            4.349499E-01  0.0
        105     G      0.0           0.0            5.289505E-01   0.0            5.078991E-01  0.0
        106     G      0.0           0.0            8.184452E-01   0.0            5.430025E-01  0.0
        201     G      0.0           0.0           -1.662521E-02   0.0            3.647701E-02  0.0
        202     G      0.0           0.0           -4.449691E-03   0.0            1.785130E-01  0.0
        203     G      0.0           0.0            1.400623E-02   0.0            3.347271E-01  0.0
        204     G      0.0           0.0            1.136803E-01   0.0            4.657716E-01  0.0
        205     G      0.0           0.0            3.221495E-01   0.0            5.550641E-01  0.0
        206     G      0.0           0.0            5.934925E-01   0.0            6.124577E-01  0.0
        301     G      0.0           0.0           -2.174967E-02   0.0            7.119847E-03  0.0
        302     G      0.0           0.0           -1.561035E-01   0.0            2.308648E-01  0.0
        303     G      0.0           0.0           -2.820587E-01   0.0            4.442662E-01  0.0
        304     G      0.0           0.0           -2.821251E-01   0.0            5.473077E-01  0.0
        305     G      0.0           0.0           -1.426077E-01   0.0            6.385375E-01  0.0
        306     G      0.0           0.0            8.810546E-02   0.0            6.702116E-01  0.0
        401     G      0.0           0.0           -6.992742E-02   0.0            1.736740E-01  0.0
        402     G      0.0           0.0           -3.394837E-01   0.0            3.304215E-01  0.0
        403     G      0.0           0.0           -5.833032E-01   0.0            4.665709E-01  0.0
        404     G      0.0           0.0           -6.367502E-01   0.0            5.304286E-01  0.0
        405     G      0.0           0.0           -5.511969E-01   0.0            5.970046E-01  0.0
        406     G      0.0           0.0           -3.347389E-01   0.0            6.219214E-01  0.0
```

Listing 8-28 Output for the 15-Degree Sweptback Wing with Piston Theory Aerodynamics (Continued)

```
                                               EIGENVECTOR FROM THE PK METHOD
EIGENVALUE =    -1.94619E+02    8.01764E+02

EIGENVECTOR
                 1.00000E+00    0.00000E+00
                 1.78271E-01    8.55037E-02
                -1.33187E-04   -5.57844E-03
                 5.87747E-03    4.75562E-03
                 6.01815E-04   -3.17303E-04

                                               EIGENVECTOR FROM THE PK METHOD
EIGENVALUE =     2.46377E+01    9.20789E+02

EIGENVECTOR
                 1.00000E+00    0.00000E+00
                 2.74293E-01   -8.44493E-02
                -2.05499E-03   -3.81114E-03
                 1.00665E-02   -1.16588E-03
                 2.97790E-04    9.50066E-06

                                               EIGENVECTOR FROM THE PK METHOD
EIGENVALUE =    -8.01337E+01    1.85544E+03

EIGENVECTOR
                -5.18031E-01    7.81684E-03
                 6.43021E-01    1.35772E-03
                 1.00000E+00    0.00000E+00
                -2.79864E-03    9.72150E-04
                 3.85070E-03   -4.21105E-04

                                                        FLUTTER  SUMMARY

    POINT =    1     MACH NUMBER =  3.0000     DENSITY RATIO =  3.9100E-01     METHOD = PK

    KFREQ           1./KFREQ        VELOCITY          DAMPING          FREQUENCY             COMPLEX   EIGENVALUE
     0.0259      3.8567291E+01   1.6000000E+03   -2.7556443E-01    7.6530746E+01   -6.6253532E+01    4.8085690E+02
     0.0265      3.7780865E+01   1.7000000E+03   -2.8125551E-01    8.3006508E+01   -7.3343742E+01    5.2154529E+02
     0.0273      3.6643333E+01   1.8000000E+03   -2.8784594E-01    9.0617615E+01   -8.1945038E+01    5.6936731E+02
     0.0285      3.5062897E+01   1.9000000E+03   -2.9809615E-01    9.9963387E+01   -9.3615379E+01    6.2808850E+02
     0.0305      3.2786278E+01   2.0000000E+03   -3.2533023E-01    1.1253123E+02   -1.1501311E+02    7.0705457E+02
     0.0325      3.0757404E+01   2.0700000E+03   -4.1089547E-01    1.2415260E+02   -1.6026440E+02    7.8007385E+02
     0.0327      3.0567787E+01   2.0800000E+03   -4.3457267E-01    1.2552623E+02   -1.7137473E+02    7.8870459E+02
     0.0329      3.0359016E+01   2.1000000E+03   -4.8547682E-01    1.2760472E+02   -1.9461896E+02    8.0176416E+02
     0.0324      3.0817970E+01   2.2000000E+03   -7.0313680E-01    1.3169031E+02   -2.9089987E+02    8.2743463E+02

    POINT =    2     MACH NUMBER =  3.0000     DENSITY RATIO =  3.9100E-01     METHOD = PK

    KFREQ           1./KFREQ        VELOCITY          DAMPING          FREQUENCY             COMPLEX   EIGENVALUE
     0.0641      1.5605687E+01   1.6000000E+03   -1.0428768E-01    1.8913515E+02   -6.1966240E+01    1.1883712E+03
     0.0587      1.7030817E+01   1.7000000E+03   -1.0906566E-01    1.8414018E+02   -6.3093773E+01    1.1569869E+03
     0.0536      1.8643053E+01   1.8000000E+03   -1.1219984E-01    1.7811095E+02   -6.2781651E+01    1.1191041E+03
     0.0486      2.0562622E+01   1.9000000E+03   -1.1105067E-01    1.7045518E+02   -5.9467724E+01    1.0710016E+03
     0.0433      2.3103600E+01   2.0000000E+03   -9.2665754E-02    1.5969286E+02   -4.6489475E+01    1.0033798E+03
     0.0391      2.5558243E+01   2.0700000E+03   -1.5269771E-02    1.4940823E+02   -7.1673226E+00    9.3875964E+02
     0.0386      2.5885735E+01   2.0800000E+03    6.6434545E-03    1.4823065E+02    3.0937262E+00    9.3136066E+02
     0.0378      2.6434685E+01   2.1000000E+03    5.3514384E-02    1.4654813E+02    2.4637730E+01    9.2078906E+02
     0.0356      2.8081648E+01   2.2000000E+03    2.4752708E-01    1.4452242E+02    1.1238486E+02    9.0806116E+02

                                                        FLUTTER  SUMMARY

    POINT =    3     MACH NUMBER =  3.0000     DENSITY RATIO =  3.9100E-01     METHOD = PK

    KFREQ           1./KFREQ        VELOCITY          DAMPING          FREQUENCY             COMPLEX   EIGENVALUE
     0.0971      1.0303611E+01   1.6000000E+03   -7.2536744E-02    2.8646112E+02   -6.5279022E+01    1.7998884E+03
     0.0919      1.0887277E+01   1.7000000E+03   -7.5485826E-02    2.8804794E+02   -6.8309341E+01    1.8098588E+03
     0.0873      1.1460998E+01   1.8000000E+03   -7.8338474E-02    2.8972449E+02   -7.1303391E+01    1.8203927E+03
     0.0832      1.2024382E+01   1.9000000E+03   -8.1100658E-02    2.9149155E+02   -7.4267746E+01    1.8314955E+03
     0.0795      1.2577048E+01   2.0000000E+03   -8.3778299E-02    2.9335022E+02   -7.7208984E+01    1.8431738E+03
     0.0772      1.2957337E+01   2.0700000E+03   -8.5605472E-02    2.9470651E+02   -7.9257645E+01    1.8516957E+03
     0.0769      1.3011213E+01   2.0800000E+03   -8.5863456E-02    2.9490402E+02   -7.9549774E+01    1.8529366E+03
     0.0762      1.3118624E+01   2.1000000E+03   -8.6377211E-02    2.9530185E+02   -8.0133705E+01    1.8554363E+03
     0.0733      1.3648745E+01   2.2000000E+03   -8.8902958E-02    2.9734808E+02   -8.3048393E+01    1.8682931E+03
```

Listing 8-28 Output for the 15-Degree Sweptback Wing with Piston Theory Aerodynamics (Continued)

```
COMPLEX EIGENVALUE = -1.946190E+02,  8.017642E+02
                                        C O M P L E X   E I G E N V E C T O R   NO.         1
                                                              (REAL/IMAGINARY)

POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
       1      G      0.0            0.0           -1.410351E-03   1.735694E-02  -8.574025E-03   0.0
                     0.0            0.0            7.894858E-04  -1.787749E-02   6.162175E-03   0.0
       2      G      0.0            0.0            1.063089E-02   1.142149E-02  -1.713100E-02   0.0
                     0.0            0.0           -1.094815E-02  -8.048949E-03  -7.133394E-04   0.0
       3      G      0.0            0.0            5.268578E-02   8.154002E-02  -4.574468E-02   0.0
                     0.0            0.0           -3.154499E-02  -4.072646E-02  -3.661815E-03   0.0
       4      G      0.0            0.0            1.376640E-01   1.076658E-01  -6.736546E-02   0.0
                     0.0            0.0           -4.966505E-02  -9.388776E-03  -2.137508E-02   0.0
       5      G      0.0            0.0            2.733906E-01   1.918517E-01  -9.964536E-02   0.0
                     0.0            0.0           -5.715957E-02  -1.964901E-02  -2.617351E-02   0.0
       6      G      0.0            0.0            4.579122E-01   2.177706E-01  -1.118616E-01   0.0
                     0.0            0.0           -5.239669E-02   1.407673E-02  -4.095432E-02   0.0
       7      G      0.0            0.0            6.774721E-01   2.708908E-01  -1.276008E-01   0.0
                     0.0            0.0           -3.334763E-02   1.136816E-02  -4.277973E-02   0.0
       8      G      0.0            0.0            9.170218E-01   2.658870E-01  -1.265991E-01   0.0
                     0.0            0.0           -7.176382E-03   2.959932E-02  -4.916488E-02   0.0
       9      G      0.0            0.0            0.0            0.0            0.0            0.0
                     0.0            0.0            0.0            0.0            0.0            0.0
      10      G      0.0            0.0            1.564192E-02   3.618494E-02  -2.280243E-02   0.0
                     0.0            0.0           -1.114328E-02  -2.517238E-02   3.168222E-03   0.0
      11      G      0.0            0.0            6.368729E-02   7.146912E-02  -3.837412E-02   0.0
                     0.0            0.0           -3.002717E-02  -2.255475E-02  -9.612271E-03   0.0
      12      G      0.0            0.0            1.554258E-01   1.326673E-01  -7.097928E-02   0.0
                     0.0            0.0           -4.455397E-02  -1.995369E-02  -1.791500E-02   0.0
      13      G      0.0            0.0            2.985154E-01   1.852203E-01  -9.365232E-02   0.0
                     0.0            0.0           -5.005112E-02  -5.807779E-03  -2.941626E-02   0.0
      14      G      0.0            0.0            4.871358E-01   2.346580E-01  -1.136638E-01   0.0
                     0.0            0.0           -4.209771E-02   7.622537E-03  -3.826180E-02   0.0
      15      G      0.0            0.0            7.101295E-01   2.633609E-01  -1.238535E-01   0.0
                     0.0            0.0           -2.202267E-02   2.003030E-02  -4.464025E-02   0.0
      16      G      0.0            0.0            9.501925E-01   2.750471E-01  -1.291921E-01   0.0
                     0.0            0.0            5.340298E-03   2.385877E-02  -4.737180E-02   0.0
      17      G      0.0            0.0           -4.317561E-04   2.821299E-02  -1.653874E-03   0.0
                     0.0            0.0           -4.229861E-05  -1.462158E-02  -4.735950E-04   0.0
      18      G      0.0            0.0            2.874272E-02   4.436449E-02  -1.212907E-02   0.0
                     0.0            0.0           -1.085238E-02  -1.275288E-02  -4.644651E-03   0.0
      19      G      0.0            0.0            9.352801E-02   1.072333E-01  -3.928709E-02   0.0
                     0.0            0.0           -2.203108E-02  -1.823393E-02  -1.133757E-02   0.0
      20      G      0.0            0.0            2.084136E-01   1.563183E-01  -6.554675E-02   0.0
                     0.0            0.0           -2.981343E-02  -8.740323E-03  -2.028175E-02   0.0
      21      G      0.0            0.0            3.702566E-01   2.107036E-01  -9.080179E-02   0.0
                     0.0            0.0           -2.707662E-02   2.790774E-03  -2.975247E-02   0.0
      22      G      0.0            0.0            5.741917E-01   2.494487E-01  -1.098735E-01   0.0
                     0.0            0.0           -1.221086E-02   1.608346E-02  -3.853690E-02   0.0
      23      G      0.0            0.0            8.061138E-01   2.723979E-01  -1.225270E-01   0.0
                     0.0            0.0            1.266234E-02   2.356734E-02  -4.439050E-02   0.0
      24      G      0.0            0.0            1.050619E+00   2.778838E-01  -1.284818E-01   0.0
                     0.0            0.0            4.243905E-02   2.640017E-02  -4.778037E-02   0.0
      25      G      0.0            0.0            0.0            0.0            0.0            0.0
                     0.0            0.0            0.0            0.0            0.0            0.0
      26      G      0.0            0.0            3.450759E-02   8.638198E-02  -4.037362E-03   0.0
                     0.0            0.0           -5.306293E-03  -1.450759E-02  -9.684628E-03   0.0
      27      G      0.0            0.0            1.231633E-01   1.282250E-01  -3.727977E-02   0.0
                     0.0            0.0           -1.277251E-02  -9.169524E-03  -1.266351E-02   0.0
      28      G      0.0            0.0            2.580873E-01   1.867248E-01  -6.230453E-02   0.0
                     0.0            0.0           -1.363294E-02  -1.132073E-03  -2.138029E-02   0.0
      29      G      0.0            0.0            4.400942E-01   2.323352E-01  -8.851524E-02   0.0
                     0.0            0.0           -3.651563E-03   1.272502E-02  -3.044416E-02   0.0
      30      G      0.0            0.0            6.597461E-01   2.676705E-01  -1.097266E-01   0.0
                     0.0            0.0            1.809240E-02   2.291513E-02  -3.922326E-02   0.0
      31      G      0.0            0.0            9.016489E-01   2.790826E-01  -1.226674E-01   0.0
                     0.0            0.0            4.760719E-02   2.784863E-02  -4.524832E-02   0.0
      32      G      0.0            0.0            1.150860E+00   2.829619E-01  -1.287299E-01   0.0
                     0.0            0.0            7.980063E-02   2.791420E-02  -4.800774E-02   0.0
      33      G      0.0            0.0           -1.594711E-03   2.214591E-02   8.471685E-03   0.0
                     0.0            0.0            8.014027E-04  -3.221692E-03  -4.244356E-03   0.0
      34      G      0.0            0.0            3.601863E-02   7.825027E-02  -2.864742E-03   0.0
                     0.0            0.0           -2.946873E-03  -1.036969E-02  -9.723596E-03   0.0
      35      G      0.0            0.0            1.325263E-01   1.513983E-01  -3.737863E-02   0.0
                     0.0            0.0           -9.411806E-03  -1.067935E-02  -1.280036E-02   0.0
      36      G      0.0            0.0            2.740625E-01   1.811309E-01  -5.890267E-02   0.0
                     0.0            0.0           -8.091401E-03   4.487140E-03  -2.183810E-02   0.0
      37      G      0.0            0.0            4.632013E-01   2.527683E-01  -9.028995E-02   0.0
                     0.0            0.0            4.227079E-03   1.240623E-02  -2.995990E-02   0.0
      38      G      0.0            0.0            6.880094E-01   2.590922E-01  -1.069388E-01   0.0
                     0.0            0.0            2.838272E-02   2.797375E-02  -4.008766E-02   0.0
      39      G      0.0            0.0            9.339656E-01   2.953009E-01  -1.263746E-01   0.0
                     0.0            0.0            5.932839E-02   2.550900E-02  -4.484631E-02   0.0
      40      G      0.0            0.0            1.183870E+00   2.676327E-01  -1.255292E-01   0.0
                     0.0            0.0            9.236998E-02   3.186627E-02  -4.877509E-02   0.0
```

Listing 8-28 Output for the 15-Degree Sweptback Wing with Piston Theory Aerodynamics (Continued)

```
COMPLEX EIGENVALUE =  2.463773E+01,  9.207891E+02
                                 C O M P L E X   E I G E N V E C T O R   NO.         2
                                                   (REAL/IMAGINARY)

POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
      1      G      0.0            0.0           -4.864316E-04  -3.344592E-03  -1.429546E-03   0.0
                    0.0            0.0           -8.864090E-04   1.970408E-02  -6.787959E-03   0.0
      2      G      0.0            0.0           -1.935482E-03   2.486905E-03  -1.778774E-02   0.0
                    0.0            0.0            1.178259E-02   7.882766E-03   5.251382E-04   0.0
      3      G      0.0            0.0            1.679465E-02   3.546819E-02  -4.941662E-02   0.0
                    0.0            0.0            3.298222E-02   4.186218E-02   2.971778E-03   0.0
      4      G      0.0            0.0            8.190697E-02   9.879222E-02  -9.075058E-02   0.0
                    0.0            0.0            4.976239E-02   4.917210E-03   2.054230E-02   0.0
      5      G      0.0            0.0            2.103971E-01   1.714154E-01  -1.275245E-01   0.0
                    0.0            0.0            5.406227E-02   1.565185E-02   2.294533E-02   0.0
      6      G      0.0            0.0            4.016670E-01   2.361879E-01  -1.557344E-01   0.0
                    0.0            0.0            4.584313E-02  -2.028428E-02   3.603094E-02   0.0
      7      G      0.0            0.0            6.437665E-01   2.852008E-01  -1.726335E-01   0.0
                    0.0            0.0            2.441062E-02  -1.421658E-02   3.534853E-02   0.0
      8      G      0.0            0.0            9.133591E-01   3.008853E-01  -1.786004E-01   0.0
                    0.0            0.0           -2.540748E-03  -3.285909E-02   4.114426E-02   0.0
      9      G      0.0            0.0            0.0            0.0            0.0            0.0
                    0.0            0.0            0.0            0.0            0.0            0.0
     10      G      0.0            0.0            2.791183E-03   7.357983E-03  -1.888024E-02   0.0
                    0.0            0.0            1.209698E-02   2.684067E-02  -3.943572E-03   0.0
     11      G      0.0            0.0            2.939385E-02   4.639218E-02  -4.883154E-02   0.0
                    0.0            0.0            3.161556E-02   2.193078E-02   9.252791E-03   0.0
     12      G      0.0            0.0            1.052149E-01   1.113185E-01  -9.016272E-02   0.0
                    0.0            0.0            4.495187E-02   1.715015E-02   1.625828E-02   0.0
     13      G      0.0            0.0            2.431163E-01   1.806540E-01  -1.251795E-01   0.0
                    0.0            0.0            4.777471E-02   9.338284E-04   2.624581E-02   0.0
     14      G      0.0            0.0            4.418868E-01   2.452551E-01  -1.543135E-01   0.0
                    0.0            0.0            3.687257E-02  -1.221723E-02   3.282717E-02   0.0
     15      G      0.0            0.0            6.883711E-01   2.875911E-01  -1.710367E-01   0.0
                    0.0            0.0            1.498629E-02  -2.337684E-02   3.739491E-02   0.0
     16      G      0.0            0.0            9.597401E-01   3.032732E-01  -1.790564E-01   0.0
                    0.0            0.0           -1.293993E-02  -2.621789E-02   3.901645E-02   0.0
     17      G      0.0            0.0           -4.893776E-04   1.108328E-02  -2.163543E-03   0.0
                    0.0            0.0            7.091220E-05   1.645105E-02   4.344013E-04   0.0
     18      G      0.0            0.0            1.598908E-02   2.960715E-02  -1.713602E-02   0.0
                    0.0            0.0            1.224190E-02   1.375972E-02   4.352926E-03   0.0
     19      G      0.0            0.0            6.776774E-02   8.645266E-02  -5.120775E-02   0.0
                    0.0            0.0            2.431994E-02   1.872217E-02   9.891785E-03   0.0
     20      G      0.0            0.0            1.738805E-01   1.472823E-01  -8.700360E-02   0.0
                    0.0            0.0            3.185228E-02   6.620797E-03   1.770299E-02   0.0
     21      G      0.0            0.0            3.393183E-01   2.151582E-01  -1.222699E-01   0.0
                    0.0            0.0            2.766973E-02  -5.870537E-03   2.552080E-02   0.0
     22      G      0.0            0.0            5.606028E-01   2.689784E-01  -1.505764E-01   0.0
                    0.0            0.0            1.145574E-02  -1.897111E-02   3.247969E-02   0.0
     23      G      0.0            0.0            8.209502E-01   3.001595E-01  -1.692739E-01   0.0
                    0.0            0.0           -1.390482E-02  -2.561611E-02   3.676556E-02   0.0
     24      G      0.0            0.0            1.099195E+00   3.087721E-01  -1.787179E-01   0.0
                    0.0            0.0           -4.342917E-02  -2.816590E-02   3.919668E-02   0.0
     25      G      0.0            0.0            0.0            0.0            0.0            0.0
                    0.0            0.0            0.0            0.0            0.0            0.0
     26      G      0.0            0.0            2.777615E-02   6.852836E-02  -1.454044E-02   0.0
                    0.0            0.0            6.987514E-03   1.788811E-02   9.100946E-03   0.0
     27      G      0.0            0.0            1.070018E-01   1.174307E-01  -5.023957E-02   0.0
                    0.0            0.0            1.655276E-02   9.947775E-03   1.021850E-02   0.0
     28      G      0.0            0.0            2.405479E-01   1.857308E-01  -8.459035E-02   0.0
                    0.0            0.0            1.801192E-02   2.847659E-04   1.788846E-02   0.0
     29      G      0.0            0.0            4.338252E-01   2.475064E-01  -1.204318E-01   0.0
                    0.0            0.0            7.827271E-03  -1.445053E-02   2.544118E-02   0.0
     30      G      0.0            0.0            6.780856E-01   2.943220E-01  -1.509461E-01   0.0
                    0.0            0.0           -1.388581E-02  -2.413009E-02   3.253265E-02   0.0
     31      G      0.0            0.0            9.532492E-01   3.113805E-01  -1.702243E-01   0.0
                    0.0            0.0           -4.274060E-02  -2.901545E-02   3.720975E-02   0.0
     32      G      0.0            0.0            1.238688E+00   3.153214E-01  -1.791321E-01   0.0
                    0.0            0.0           -7.399355E-02  -2.900999E-02   3.918502E-02   0.0
     33      G      0.0            0.0           -7.002870E-04   1.784369E-02   3.649303E-03   0.0
                    0.0            0.0           -7.989816E-04   4.716509E-03   4.425867E-03   0.0
     34      G      0.0            0.0            3.179739E-02   6.539295E-02  -1.331488E-02   0.0
                    0.0            0.0            4.876892E-03   1.290823E-02   8.914609E-03   0.0
     35      G      0.0            0.0            1.197925E-01   1.383678E-01  -5.029335E-02   0.0
                    0.0            0.0            1.386667E-02   1.264960E-02   9.916334E-03   0.0
     36      G      0.0            0.0            2.622851E-01   1.868178E-01  -8.165038E-02   0.0
                    0.0            0.0            1.340461E-02  -6.126273E-03   1.823485E-02   0.0
     37      G      0.0            0.0            4.651751E-01   2.670472E-01  -1.214961E-01   0.0
                    0.0            0.0            1.280528E-03  -1.280233E-02   2.458131E-02   0.0
     38      G      0.0            0.0            7.171724E-01   2.917350E-01  -1.491573E-01   0.0
                    0.0            0.0           -2.244029E-02  -2.977178E-02   3.344839E-02   0.0
     39      G      0.0            0.0            9.978645E-01   3.244500E-01  -1.733323E-01   0.0
                    0.0            0.0           -5.232643E-02  -2.542652E-02   3.644723E-02   0.0
     40      G      0.0            0.0            1.284913E+00   3.049084E-01  -1.768887E-01   0.0
                    0.0            0.0           -8.429529E-02  -3.402103E-02   4.016655E-02   0.0
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Listing 8-28 Output for the 15-Degree Sweptback Wing with Piston Theory Aerodynamics (Continued)

```
COMPLEX EIGENVALUE = -8.013371E+01,  1.855436E+03
                                          C O M P L E X   E I G E N V E C T O R   NO.          3
                                                              (REAL/IMAGINARY)

POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
      1      G      0.0            0.0             1.047920E-02  -1.617767E-01   6.362339E-02   0.0
                    0.0            0.0            -3.401038E-05   8.064013E-04  -2.729512E-04   0.0
      2      G      0.0            0.0            -8.347771E-02  -2.251795E-02   6.046910E-02   0.0
                    0.0            0.0             4.614047E-04   2.850964E-04   2.436861E-05   0.0
      3      G      0.0            0.0            -2.404819E-01  -2.885968E-01   1.501465E-01   0.0
                    0.0            0.0             1.252576E-03   1.604266E-03   1.460441E-05   0.0
      4      G      0.0            0.0            -3.500665E-01   8.461757E-02   1.436280E-01   0.0
                    0.0            0.0             1.914446E-03   2.333258E-04   3.370527E-04   0.0
      5      G      0.0            0.0            -3.269584E-01   6.632644E-02   2.455709E-01   0.0
                    0.0            0.0             2.475442E-03   1.290557E-03  -3.039046E-04   0.0
      6      G      0.0            0.0            -1.454043E-01   4.847316E-01   2.347115E-01   0.0
                    0.0            0.0             3.376214E-03   8.572310E-04  -6.604888E-04   0.0
      7      G      0.0            0.0             1.704016E-01   4.330379E-01   3.323780E-01   0.0
                    0.0            0.0             4.781527E-03   2.182825E-03  -1.420169E-03   0.0
      8      G      0.0            0.0             5.180790E-01   6.047416E-01   3.207350E-01   0.0
                    0.0            0.0             6.742940E-03   1.981041E-03  -1.562426E-03   0.0
      9      G      0.0            0.0             0.0            0.0            0.0            0.0
                    0.0            0.0             0.0            0.0            0.0            0.0
     10      G      0.0            0.0            -1.057462E-01  -2.063069E-01   1.130666E-01   0.0
                    0.0            0.0             4.717513E-04   1.057373E-03  -1.629300E-04   0.0
     11      G      0.0            0.0            -2.762330E-01  -1.402375E-01   1.088355E-01   0.0
                    0.0            0.0             1.222850E-03   8.375988E-04   2.516959E-04   0.0
     12      G      0.0            0.0            -3.949783E-01  -5.918887E-02   2.097838E-01   0.0
                    0.0            0.0             1.846614E-03   8.736462E-04   1.386952E-04   0.0
     13      G      0.0            0.0            -3.893057E-01   1.900489E-01   2.336975E-01   0.0
                    0.0            0.0             2.539959E-03   9.244682E-04  -1.949048E-04   0.0
     14      G      0.0            0.0            -2.115109E-01   3.823791E-01   2.845052E-01   0.0
                    0.0            0.0             3.563229E-03   1.427989E-03  -8.042280E-04   0.0
     15      G      0.0            0.0             8.650444E-02   5.122021E-01   3.192022E-01   0.0
                    0.0            0.0             5.139691E-03   1.970882E-03  -1.336835E-03   0.0
     16      G      0.0            0.0             4.320273E-01   5.310512E-01   3.488120E-01   0.0
                    0.0            0.0             7.162603E-03   2.309329E-03  -1.679773E-03   0.0
     17      G      0.0            0.0            -7.613319E-04  -2.004177E-01   4.829248E-03   0.0
                    0.0            0.0             2.032110E-06   6.397676E-04   3.248140E-06   0.0
     18      G      0.0            0.0            -1.725589E-01  -1.862808E-01   5.515521E-02   0.0
                    0.0            0.0             4.765802E-04   5.518922E-04   1.614778E-04   0.0
     19      G      0.0            0.0            -3.939156E-01  -2.750368E-01   1.920642E-01   0.0
                    0.0            0.0             1.025072E-03   9.221211E-04   2.477137E-04   0.0
     20      G      0.0            0.0            -5.811859E-01  -5.805577E-02   2.663949E-01   0.0
                    0.0            0.0             1.746014E-03   1.027209E-03   1.078458E-04   0.0
     21      G      0.0            0.0            -6.031808E-01   1.605820E-01   3.155970E-01   0.0
                    0.0            0.0             2.740918E-03   1.470712E-03  -3.312527E-04   0.0
     22      G      0.0            0.0            -4.532699E-01   3.807673E-01   3.374183E-01   0.0
                    0.0            0.0             4.232312E-03   1.976250E-03  -9.140982E-04   0.0
     23      G      0.0            0.0            -1.755991E-01   4.895138E-01   3.558339E-01   0.0
                    0.0            0.0             6.219317E-03   2.386376E-03  -1.427018E-03   0.0
     24      G      0.0            0.0             1.553009E-01   5.316419E-01   3.637772E-01   0.0
                    0.0            0.0             8.504001E-03   2.511239E-03  -1.747523E-03   0.0
     25      G      0.0            0.0             0.0            0.0            0.0            0.0
                    0.0            0.0             0.0            0.0            0.0            0.0
     26      G      0.0            0.0            -2.165249E-01  -4.755317E-01   6.698423E-02   0.0
                    0.0            0.0             2.569513E-04   6.976659E-04   3.854881E-04   0.0
     27      G      0.0            0.0            -5.767798E-01  -3.075665E-01   2.786430E-01   0.0
                    0.0            0.0             8.107381E-04   8.762083E-04   2.881770E-04   0.0
     28      G      0.0            0.0            -8.201619E-01  -1.152419E-01   3.485368E-01   0.0
                    0.0            0.0             1.663227E-03   1.407193E-03   8.881915E-05   0.0
     29      G      0.0            0.0            -8.754129E-01   1.773268E-01   3.843214E-01   0.0
                    0.0            0.0             3.035255E-03   1.998125E-03  -4.315371E-04   0.0
     30      G      0.0            0.0            -7.342857E-01   3.760196E-01   3.858066E-01   0.0
                    0.0            0.0             5.001603E-03   2.559543E-03  -1.057288E-03   0.0
     31      G      0.0            0.0            -4.605806E-01   5.040348E-01   3.773414E-01   0.0
                    0.0            0.0             7.384573E-03   2.710759E-03  -1.550985E-03   0.0
     32      G      0.0            0.0            -1.330768E-01   5.184990E-01   3.780205E-01   0.0
                    0.0            0.0             9.902165E-03   2.718639E-03  -1.820349E-03   0.0
     33      G      0.0            0.0             2.970025E-03  -1.751309E-01  -3.174018E-02   0.0
                    0.0            0.0            -3.633523E-05   1.330563E-04   1.877310E-04   0.0
     34      G      0.0            0.0            -2.432260E-01  -3.895693E-01   8.364099E-02   0.0
                    0.0            0.0             1.613844E-04   5.489420E-04   3.924676E-04   0.0
     35      G      0.0            0.0            -6.529070E-01  -4.444935E-01   3.200474E-01   0.0
                    0.0            0.0             7.303757E-04   1.052046E-03   2.990064E-04   0.0
     36      G      0.0            0.0            -9.143163E-01  -1.480589E-03   3.592404E-01   0.0
                    0.0            0.0             1.639469E-03   1.386720E-03   1.046184E-04   0.0
     37      G      0.0            0.0            -9.792700E-01   8.033113E-02   4.260781E-01   0.0
                    0.0            0.0             3.152308E-03   2.297115E-03  -4.790440E-04   0.0
     38      G      0.0            0.0            -8.333775E-01   4.936429E-01   3.754407E-01   0.0
                    0.0            0.0             5.280297E-03   2.577077E-03  -1.068973E-03   0.0
     39      G      0.0            0.0            -5.617344E-01   3.923703E-01   4.079929E-01   0.0
                    0.0            0.0             7.799421E-03   2.929659E-03  -1.625045E-03   0.0
     40      G      0.0            0.0            -2.275632E-01   6.476611E-01   3.530865E-01   0.0
                    0.0            0.0             1.037391E-02   2.592625E-03  -1.794198E-03   0.0
```

Flutter Analysis of a Square Simply Supported Panel (Examples HA145HA and HA145HB)

Interest in the flutter of flat and curved panels (plates) began in Germany during World War II as a possible explanation for in-flight failures of V-2 missiles. Current interest is concerned with the design of surface structures of aircraft cruising at high supersonic speeds. The literature on the analysis of fluttering panels and design to prevent their flutter has been surveyed by Rodden (1977) [Reference 42]. Rectangular flat panels with simple and clamped supports have been studied extensively using various aerodynamic approximations. The assumption of flow on only one side of the panel is realized in MSC Nastran by using only half of the air density of the airstream in the flutter analysis. The Piston Theory in MSC Nastran is applicable to panels at Mach numbers perhaps as low as $m = 1.5$, and the ZONA51 supersonic aerodynamics are valid in the low supersonic regime down to a Mach number close to $m = 1.0$. Two examples are considered here, both of a square panel with simply supported edges at Mach numbers $m = 2.0$ and 3.0 at sea level and neglecting structural damping. These are Example HA145HA, using Piston Theory, and Example HA145HB, using ZONA51. The configuration is shown in Figure 8-13.

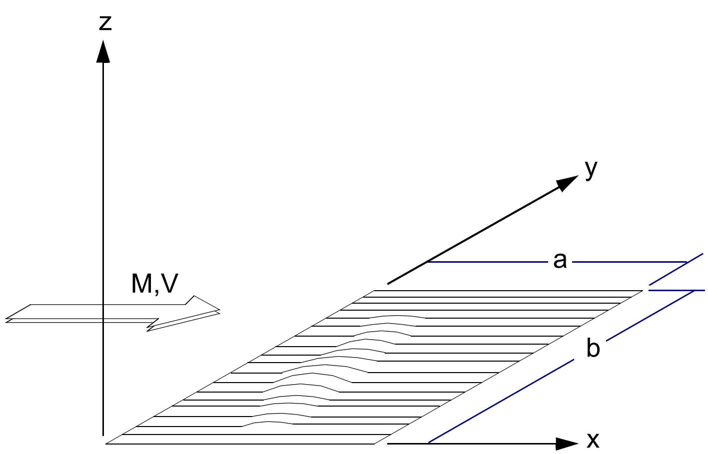

Figure 8-13 Rectangular Panel and Coordinate System

The panel is assumed to be square with sides $a = b = 10.0$ in. and thickness $t = 0.041$ in. and to be made of aluminum with moduli $E = 10.3 \times 10^6$ and $G = 3.9 \times 10^6$ psi and density $r = 0.100$ lb/in^3. The panel is modeled with 100 square CQUAD4 elements as shown in Figure 8-14. The model is contained in input file PANEL_STRUCT.DAT that contains the 121 GRID entries and the 100 CQUAD4 entries, as well as the SPC1 entries required to restrain rigid body rotation, to obtain the simple supports around the edges, and to restrain the drilling degrees of freedom of the QUAD4 elements. PANEL_STRUC.DAT also contains the panel properties on the PSHELL and MAT1 entries; transverse shear effects are neglected. The PARAMs GRDPNT, WTMASS, and COUPMASS are also included. PARAM,WTMASS converts the input weight data to mass data, and PARAM,COUPMASS generates a

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coupled (not a consistent) mass matrix for the vibration analysis. The structural data are shown in Listing 8-29 and are included in the flutter analyses by the request INCLUDE PANEL_STRUCT.DAT.

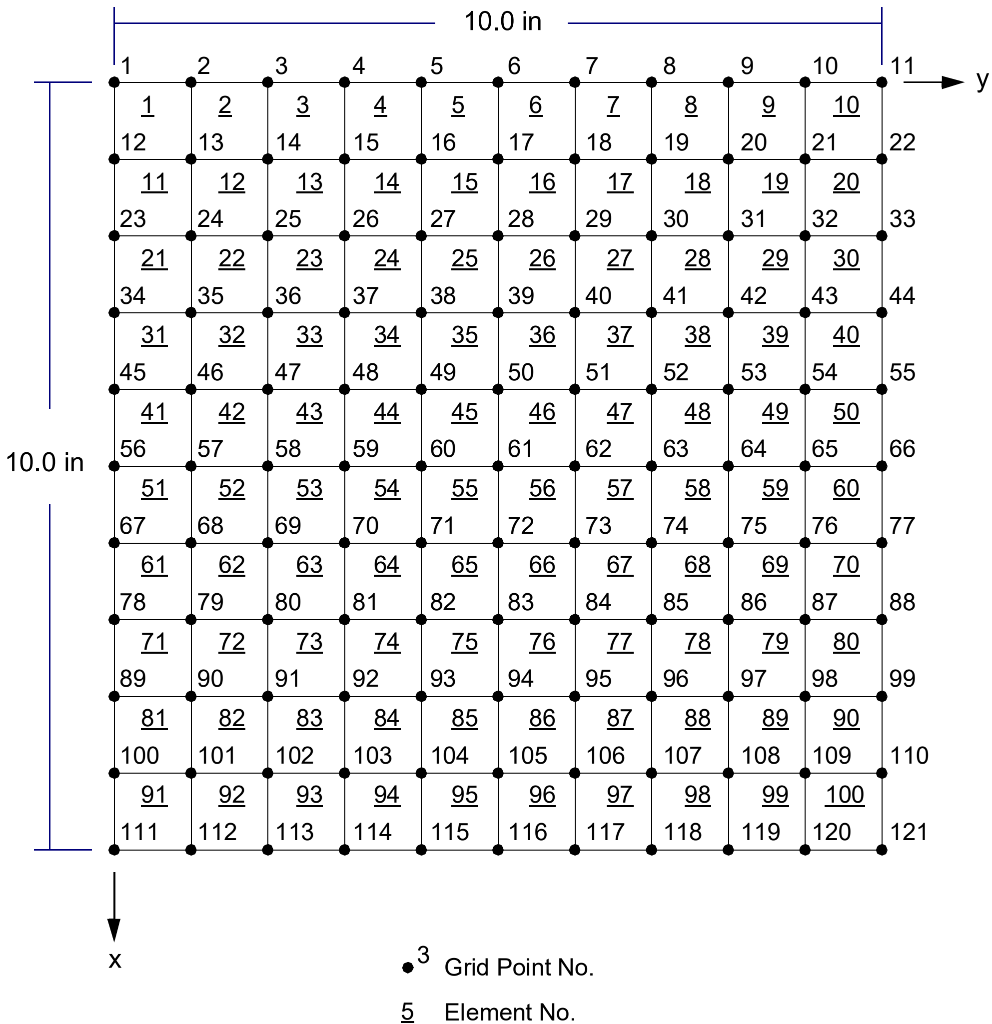


Figure 8-14 Structural Grid Points and QUAD4 Elements

Example HA145HA uses Piston Theory and models the panel surface by 10 CAERO5 entries along the chord, each being divided into 10 equal spanwise strips as shown in Figure 8-15. Each CAERO5 entry specifies the one PAERO5, 1001 entry that provides the two Mach numbers, $m = 2.0$ and 3.0, and zero trim angle of attack data on AEFACT 20. Each CAERO5 entry also specifies the NSPAN = 10 equal strip widths, the Van Dyke correction to Piston Theory by NTHRY = 1, the NTHICK = 10 zero thickness integrals on AEFACT 10, and the spanwise strip geometry with a unit chord. The linear spline SPLINE2 is consistent with the rigid chord assumption of Piston Theory. Ten SPLINE2 entries connect each of the 10 spanwise strips to their respective forward and aft GRIDs via 10 SET1 entries and 10 CORD2R elastic axes through the midchord of each spanwise strip. The flutter analysis entries begin with the AERO entry, which specifies the aerodynamic coordinate system with its positive x-axis streamwise to be the basic coordinate system, the reference chord as 10.0 in., and the sea-level density. The MKAERO1 entry specifies the two Mach numbers $m = 2.0$ and 3.0 and the four reduced frequencies, $k = 0.001$, 0.1, 0.2, and 0.4, for the generation of the Piston Theory aerodynamic influence coefficients.

The FLUTTER entry specifies the PK-method and requests four modes output from the flutter analysis. FLFACT 1 introduces the factor of 0.5 on the density to account for the air only flowing on one side of the panel. FLFACT 2 specifies the two Mach numbers. FLFACT 3 specifies the velocities for the PK-flutter analysis in in/s and PARAM,VREF,12.0 provides the factor to output the flutter speeds in the Flutter Summary table in units of ft/s. The vibration analysis method is specified by the EIGR entry as the Givens method and requests 15 modes to be normalized on their largest components. All 15 modes are used in the flutter analysis. Finally, PARAM,OPPHIPA, along with a DISP request in Case Control, provides the deflections of all grid points including the aerodynamic points which, for Piston Theory, are located at the quarter-chord of the centerline of each aerodynamic box. It should be mentioned that the flutter mode of the square panel is symmetric about its streamwise centerline and that the 15 modes selected include both symmetric and antisymmetric modes. It is not likely that the 10×10 CQUAD4 model of the panel structure will have an accurate 15th mode, but the correlation shown below indicates that it is a reasonable model.

Case Control Commands

The Case Control Section includes the title, subtitle, label, ECHO = BOTH, METHOD = 20 for the vibration analysis, and FMETHOD = 30 for the PK flutter analysis. SPC = 1 includes all of the Bulk Data constraints. DISP = 10 and SET 10 = 1 through 999,999 requests the vibration modes at all grid points including the aerodynamic grid points. BEGIN BULK concludes the Case Control Section. The Executive Control Section includes ID MSC, HA145HA, TIME 25 minutes, and SOL 145, and concludes with CEND.

Output

The input data are shown in Listing 8-30 and Listing 8-31. Selected output data are shown in Listing 8-32 and are discussed below.

The output from the GRID POINT WEIGHT GENERATOR checks some of the structural data input with the weight of 0.410 lbs and centroid at $x = y = 5.0 \text{ in}$. The first vibration frequency is $f_1 = 78.57 \text{ Hz}$. This agrees with the theoretical value, with transverse shear effects neglected, of

$$f_1 = (\pi / a^2)\sqrt{(gD/\rho t)} = 78.28 \text{ Hz}$$

where the plate stiffness

$$D = Et^3/12(1-\nu^2) = 65.93 \text{ in-lb}$$

based on Poisson's ratio $\nu = E/2G-1 = 0.3205$. The second theoretical frequency is

$$f_2 = (5\pi/2a^2)\sqrt{(gD/\rho t)} = 195.70 \text{ Hz}$$

and corresponds to a calculated value of 200.43 Hz, and the limitations of the 10×10 element structural model are apparent in the loss in accuracy of the calculated second frequency. Although 15 modes are used in the flutter analysis, the flutter is caused primarily by the coupling between the first two symmetric modes and great accuracy is not required in the higher modes. The first three vibration modes follow the frequency output. Since the second and third modes have identical frequencies, any linear combination of the second and third modes shown are also modes. Appropriate combinations of these modes would correspond to the second symmetric and second antisymmetric modes.

The flutter data summaries for the first four modes are shown next, and the dampings and frequencies are plotted in Figure 8-16 for the critical second mode at the two Mach numbers. At a Mach number $m = 2.0$ the flutter speed is $V = 1919 \text{ ft/s}$, and at $m = 3.0$ the speed is $V = 2436 \text{ ft/s}$; the flutter frequencies are 171 and 173 Hz, respectively. The nondimensional stability parameter customarily used in panel flutter studies is

$$\lambda_{cr} = 2\bar{q}a^3/\beta D$$

where $\beta^2 = M^2-1$. The values of λ for the two Mach numbers are found to be $\lambda_{cr} = 532$ at $m = 2.0$ and $\lambda_{cr} = 526$ at $m = 3.0$. These compare reasonably well with the theoretical values given by Hedgepeth (1957, Table 2 [Reference 27]) of $\lambda_{cr} = 492$ at $m = 2.0$ and $\lambda_{cr} = 499$ at $m = 3.0$.

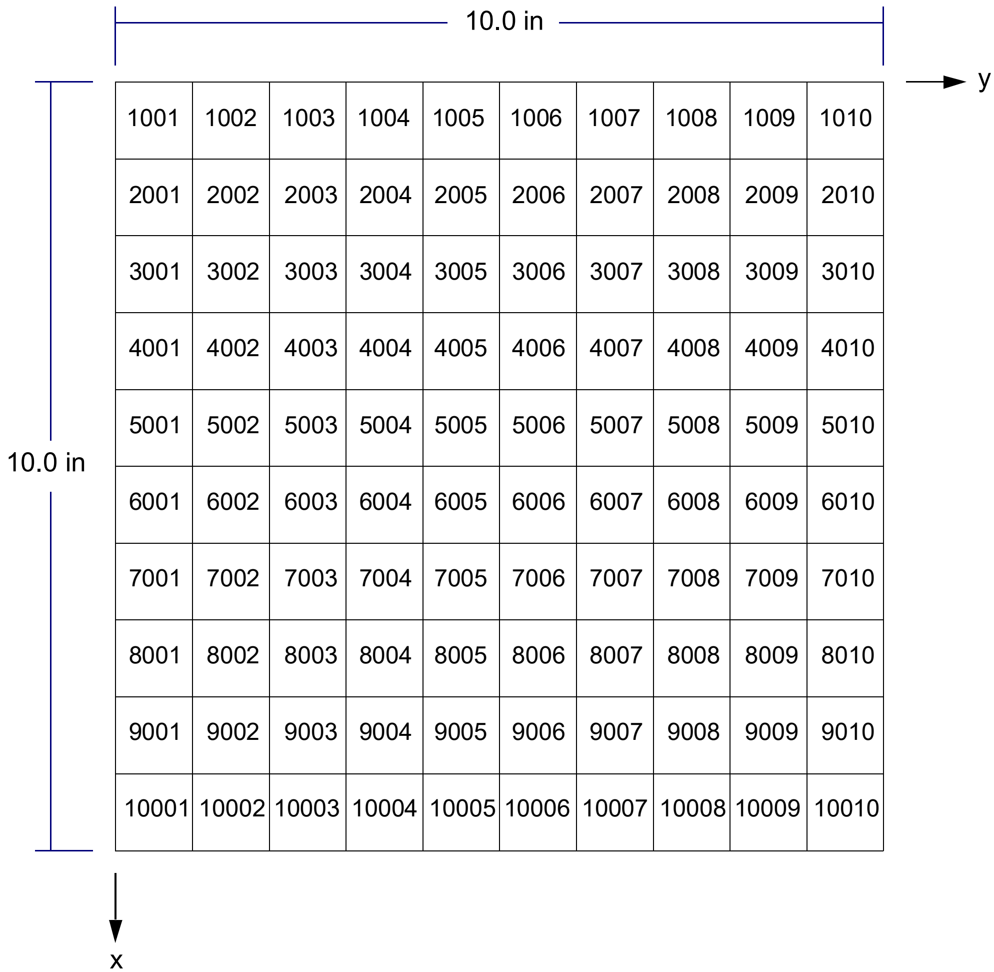


Figure 8-15 CAERO5 Entries for 10 Chordwise Panels Each Divided into 10 Spanwise Strips

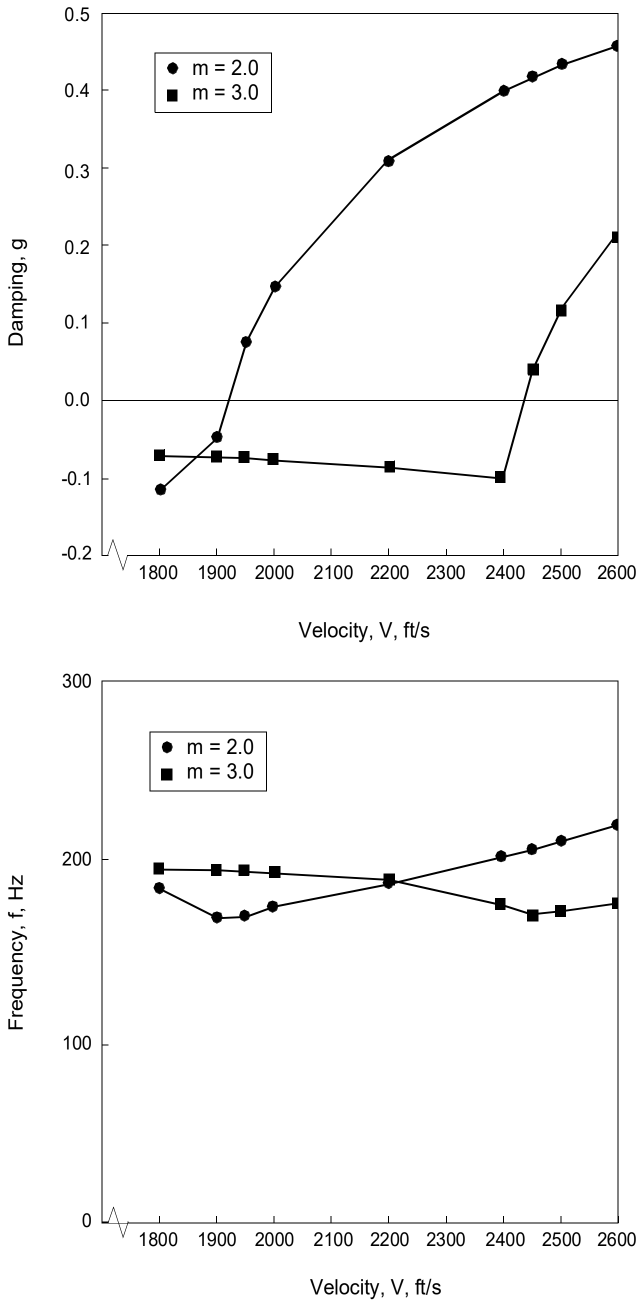


Figure 8-16 Critical Flutter V-g and V-f Curves for Piston Theory

Example HA145HB uses ZONA51 supersonic aerodynamics and models the panel surface by a single CAERO1 entry divided into 100 equal boxes. It also models the regions to either side of the panel by square CAERO1 panels that have no motion so that the center panel behaves as a panel within a larger surface rather than as a wing. The lateral CAERO1 panels prevent the edges of the central CAERO1 panel from acting like tips on an isolated wing. The aspect ratio of the lateral panels must be such that the Mach lines from the forward outboard corners do not intersect the side edges of the central panel as shown in Figure 8-17. The square lateral panels chosen here would permit an analysis Mach number as low as $\sqrt{2} = 1.414$. The Bulk Data Section is similar to that described above for Piston Theory. The three CAERO1 entries specify the panel and its lateral counterparts, each divided into 10 equal spanwise and 10 equal chordwise boxes. The PAERO1 entry is required. The 10 spanwise linear splines are the same as those required to obtain accurate interpolation at the aerodynamic grid points for Piston Theory; note that Remark 1 on the SPLINE1 entry also applies to the SPLINE2 entry and the box numbering for each SPLINE2 is taken from Figure 8-18. The SET1 and CORD2R entries are those used in the Piston Theory analysis. The remainder of the Bulk Data entries are the same as in the Piston Theory analysis.

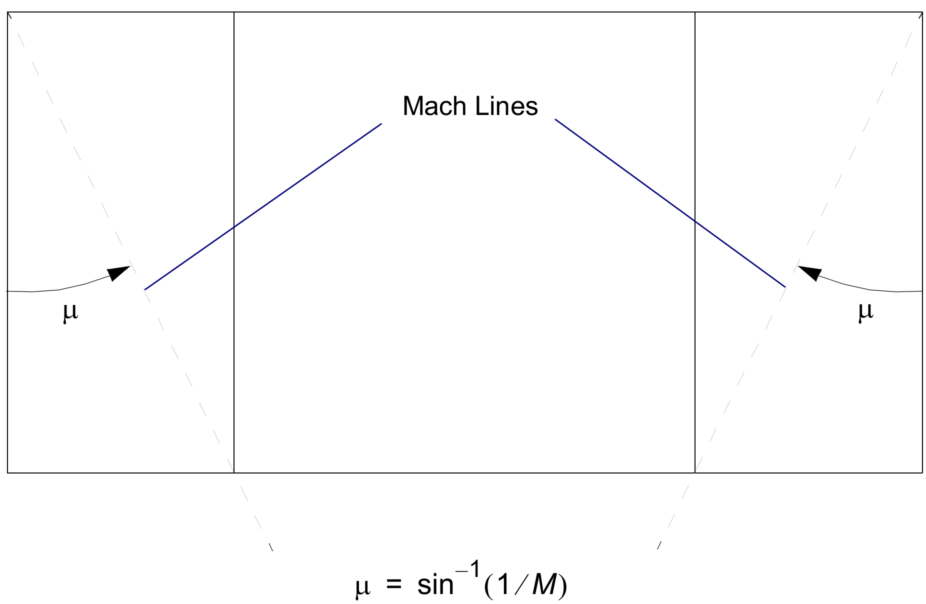


Figure 8-17 Mach Wave Interference from Lateral Panels

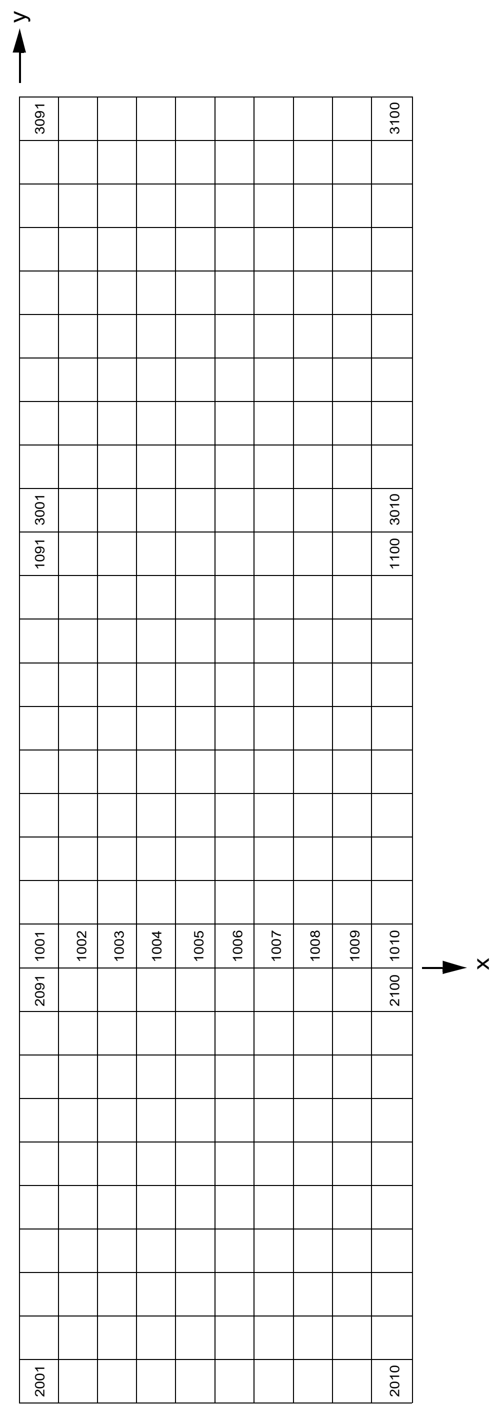
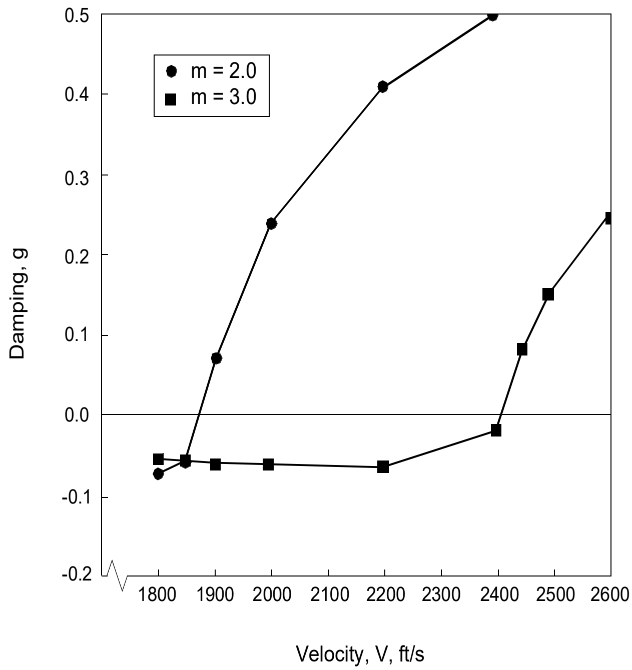


Figure 8-18 CAERO1 Box Numbering for ZONA51 Supersonic Aerodynamics

The input data are shown in Listing 8-33 and Listing 8-34 and the Flutter Summary tables are shown in Listing 8-35. The dampings and frequencies are plotted in Figure 8-19, again for the critical second mode at the two Mach numbers. At $m = 2.0$ the flutter speed is $V = 1873$ ft/s, and at $m = 3.0$ the speed is $V = 2410$ ft/s; the flutter frequencies are 169 and 173 Hz, respectively. The values of the stability parameter are $\lambda_{cr} = 507$ at $m = 2.0$ and $\lambda_{cr} = 515$ at $m = 3.0$. These compare reasonably well with the Piston Theory results above and more closely with the values of Hedgepeth (1957, Table 2 [Reference 27]). ZONA51 appears to be more conservative than Piston Theory. The panel stability parameters are compared in Table 8-4 for the various methods at the two Mach numbers. One would expect better agreement between Piston Theory and ZONA51 at the higher Mach number, and this is the case.

Table 8-4 The Panel Stability Parameter λ_{cr}

Mach Number	Piston Theory	ZONA51	Hedgepeth (1957)
2.0	532	507	492
3.0	526	515	499



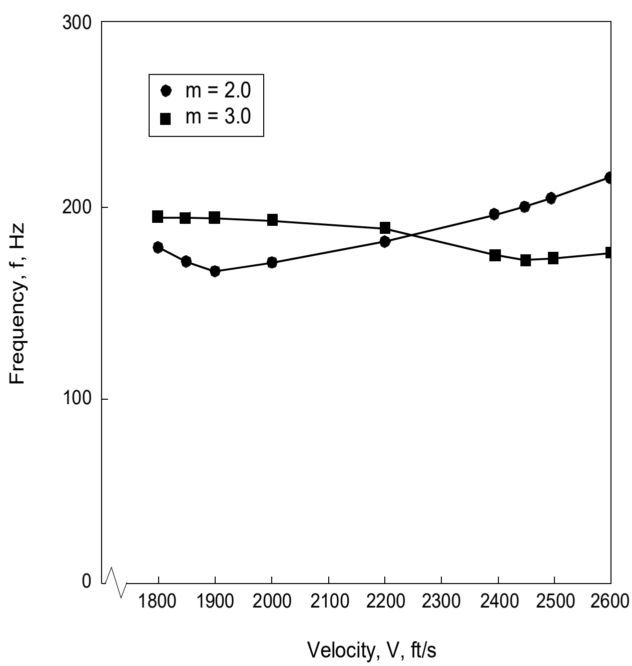


Figure 8-19 Critical Flutter V-g and V-f Curves for ZONA51 Aerodynamics

Listing 8-29 Bulk Data Entries for PANEL_STRUCT.DAT Input File

```
$
$       REPLICATION IS A LIMITED DATA GENERATION CAPABILITY OF MSC/NASTRAN.
$       IT CAN BE USED HERE FOR GRID POINT GENERATION AND QUAD4 ELEMENT
$       GEOMETRY GENERATION BECAUSE OF THE UNIFORM DIVISIONS OF THE STRUCTURAL
$       MODEL IN THIS EXAMPLE.
$
GRID    1               0.0     0.0     0.0
=       *1      =       =       *1.0    =
=9
GRID    12              1.0     0.0     0.0
=       *1      =       =       *1.0    =
=9
GRID    23              2.0     0.0     0.0
=       *1      =       =       *1.0    =
=9
GRID    34              3.0     0.0     0.0
=       *1      =       =       *1.0    =
=9
GRID    45              4.0     0.0     0.0
=       *1      =       =       *1.0    =
=9
GRID    56              5.0     0.0     0.0
=       *1      =       =       *1.0    =
=9
GRID    67              6.0     0.0     0.0
=       *1      =       =       *1.0    =
=9
GRID    78              7.0     0.0     0.0
=       *1      =       =       *1.0    =
=9
GRID    89              8.0     0.0     0.0
=       *1      =       =       *1.0    =
=9
GRID    100             9.0     0.0     0.0
=       *1      =       =       *1.0    =
=9
GRID    111             10.0    0.0     0.0
=       *1      =       =       *1.0    =
=9
$
CQUAD4  1       1       1       2       13      12
=       *1      =       *1      *1      *1      *1
=8
CQUAD4  11      1       12      13      24      23
=       *1      =       *1      *1      *1      *1
=8
CQUAD4  21      1       23      24      35      34
=       *1      =       *1      *1      *1      *1
=8
CQUAD4  31      1       34      35      46      45
=       *1      =       *1      *1      *1      *1
=8
CQUAD4  41      1       45      46      57      56
=       *1      =       *1      *1      *1      *1
=8
CQUAD4  51      1       56      57      68      67
=       *1      =       *1      *1      *1      *1
=8
CQUAD4  61      1       67      68      79      78
=       *1      =       *1      *1      *1      *1
=8
CQUAD4  71      1       78      79      90      89
=       *1      =       *1      *1      *1      *1
=8
CQUAD4  81      1       89      90      101     100
=       *1      =       *1      *1      *1      *1
=8
CQUAD4  91      1       100     101     112     111
=       *1      =       *1      *1      *1      *1
=8
$
```

Listing 8-29 Bulk Data Entries for PANEL_STRUCT.DAT Input File (Continued)

```
SPC1    1       1       1
SPC1    1       2       1       110
SPC1    1       3       1       THRU    11
SPC1    1       3       111     THRU    121
SPC1    1       3       12      22      23      33      34      44      +SP1
+SP1    45      55      56      66      67      77      78      88      +SP2
+SP2    89      99      100     110
SPC1    1       6       1       THRU    121
$
$ PROPERTY AND MATERIAL BULK DATA ENTRIES
$
PSHELL  1       10      .041    10
$
MAT1    10      1.03+7  3.9+6           .1
$
PARAM   GRDPNT  1
$
PARAM   WTMASS  .0025907
$
PARAM   COUPMASS1
$
```

Listing 8-30 Input Data for Flutter Analysis of Square Panel Using Piston Theory

```
   N A S T R A N   E X E C U T I V E   C O N T R O L   D E C K   E C H O


ID MSC, HA145HA
TIME 25
SOL 145
CEND


3D PANEL FLUTTER                                                    DECEMBER  17, 1993  MSC/NASTRAN  12/15/93   PAGE     2
  PINNED EDGES
  PISTON THEORY AERO WITH VAN DYKE CORRECTION, EXAMPLE HA145HA
                                   C A S E   C O N T R O L   D E C K   E C H O
             CARD
             COUNT
              1      $
              2      TITLE = 3D PANEL FLUTTER
              3      SUBTI = PINNED EDGES
              4      LABEL = PISTON THEORY AERO WITH VAN DYKE CORRECTION, EXAMPLE HA145HA
              5        ECHO     = BOTH
              6        METHOD   = 20
              7        FMETHOD  = 30
              8        SPC      = 1
              9        SET   10 = 1 THRU 999999
             10        DISP     = 10
             11      BEGIN BULK


3D PANEL FLUTTER                                                                                                PAGE     3
  PINNED EDGES
 PISTON THEORY AERO WITH VAN DYKE CORRECTION, EXAMPLE HA145HA
                                        I N P U T   B U L K   D A T A   D E C K   E C H O
                              .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                              $
                              INCLUDE PANEL_STRUCT.DAT
                              $
                              $ TEN CAERO5 ENTRIES FOR PANEL SURFACE
                              $
                              $       EID     PID     CP      NSPAN   LSPAN   NTHRY   NTHICK
                              CAERO5  1001    1001            10              1       10              +CA501
                              $       X1      Y1      Z1      X12     X4      Y4      Z4      X43
                              +CA501  0.0     0.0     0.0     1.0     0.0     10.0    0.0     1.0
                              $
                              CAERO5  2001    1001            10              1       10              +CA502
                              +CA502  1.0     0.0     0.0     1.0     1.0     10.0    0.0     1.0
                              CAERO5  3001    1001            10              1       10              +CA503
                              +CA503  2.0     0.0     0.0     1.0     2.0     10.0    0.0     1.0
                              CAERO5  4001    1001            10              1       10              +CA504
                              +CA504  3.0     0.0     0.0     1.0     3.0     10.0    0.0     1.0
                              CAERO5  5001    1001            10              1       10              +CA505
                              +CA505  4.0     0.0     0.0     1.0     4.0     10.0    0.0     1.0
                              CAERO5  6001    1001            10              1       10              +CA506
                              +CA506  5.0     0.0     0.0     1.0     5.0     10.0    0.0     1.0
                              CAERO5  7001    1001            10              1       10              +CA507
                              +CA507  6.0     0.0     0.0     1.0     6.0     10.0    0.0     1.0
                              CAERO5  8001    1001            10              1       10              +CA508
                              +CA508  7.0     0.0     0.0     1.0     7.0     10.0    0.0     1.0
                              CAERO5  9001    1001            10              1       10              +CA509
                              +CA509  8.0     0.0     0.0     1.0     8.0     10.0    0.0     1.0
                              CAERO5  10001   1001            10              1       10              +CA510
                              +CA510  9.0     0.0     0.0     1.0     9.0     10.0    0.0     1.0
                              $
                              $ THICKNESS INTEGRALS
                              AEFACT  10      0.0     0.0     0.0     0.0     0.0     0.0
                              $
                              $       PID     NALPHA  LALPHA  NXIS    LXIS    NTAUS   LTAUS
                              PAERO5  1001    1       20                                              +PA5
                              $       CAOC1   CAOC2   ETC
                              +PA5    0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     +PA51
                              +PA51   0.0     0.0
                              $
                              $ MACH, ALPHA COMBOS
```

Listing 8-30 Input Data for Flutter Analysis of Square Panel Using Piston Theory (Continued)

```
$       SID     MACH1   ALPHA11 MACH2   ALPHA21 ETC
AEFACT  20      2.0     0.0     3.0     0.0
$
$       EID     CAERO   ID1     ID2     SETG    DZ      DTOR    CID     +SPL
SPLINE2 1001    1001    1001    1010    1001    0.0     1.0     1       +SPL1
$+SPL   DTHX    DTHY
+SPL1   -1.0    -1.0
$
SPLINE2 2001    2001    2001    2010    2001    0.0     1.0     2       +SPL2
+SPL2   -1.0    -1.0
SPLINE2 3001    3001    3001    3010    3001    0.0     1.0     3       +SPL3
+SPL3   -1.0    -1.0
SPLINE2 4001    4001    4001    4010    4001    0.0     1.0     4       +SPL4
+SPL4   -1.0    -1.0
SPLINE2 5001    5001    5001    5010    5001    0.0     1.0     5       +SPL5
+SPL5   -1.0    -1.0
SPLINE2 6001    6001    6001    6010    6001    0.0     1.0     6       +SPL6
+SPL6   -1.0    -1.0
SPLINE2 7001    7001    7001    7010    7001    0.0     1.0     7       +SPL7
+SPL7   -1.0    -1.0
SPLINE2 8001    8001    8001    8010    8001    0.0     1.0     8       +SPL8
+SPL8   -1.0    -1.0
SPLINE2 9001    9001    9001    9010    9001    0.0     1.0     9       +SPL9
+SPL9   -1.0    -1.0
SPLINE2 10001   10001   10001   10010   10001   0.0     1.0     10      +SPL10
+SPL10  -1.0    -1.0
$
$       SID     G1      G2      G3      ETC
SET1    1001    1       THRU    22
SET1    2001    12      THRU    33
SET1    3001    23      THRU    44
SET1    4001    34      THRU    55
SET1    5001    45      THRU    66
SET1    6001    56      THRU    77
SET1    7001    67      THRU    88
SET1    8001    78      THRU    99
SET1    9001    89      THRU    110
SET1    10001   100     THRU    121
$
$       CID     RID     A1      A2      A3      B1      B2      B3      +CRD
CORD2R  1               0.5     0.0     0.0     0.5     0.0     1.0     +CRD1
$       C1      C2      C3
+CRD1   20.0    0.0     0.0
CORD2R  2               1.5     0.0     0.0     1.5     0.0     1.0     +CRD2
+CRD2   20.0    0.0     0.0
CORD2R  3               2.5     0.0     0.0     2.5     0.0     1.0     +CRD3
+CRD3   20.0    0.0     0.0
CORD2R  4               3.5     0.0     0.0     3.5     0.0     1.0     +CRD4
+CRD4   20.0    0.0     0.0
CORD2R  5               4.5     0.0     0.0     4.5     0.0     1.0     +CRD5
+CRD5   20.0    0.0     0.0
CORD2R  6               5.5     0.0     0.0     5.5     0.0     1.0     +CRD6
+CRD6   20.0    0.0     0.0
CORD2R  7               6.5     0.0     0.0     6.5     0.0     1.0     +CRD7
+CRD7   20.0    0.0     0.0
CORD2R  8               7.5     0.0     0.0     7.5     0.0     1.0     +CRD8
+CRD8   20.0    0.0     0.0
CORD2R  9               8.5     0.0     0.0     8.5     0.0     1.0     +CRD9
+CRD9   20.0    0.0     0.0
CORD2R  10              9.5     0.0     0.0     9.5     0.0     1.0     +CRD10
+CRD10  20.0    0.0     0.0
$
AERO    0       0       10.0    1.1468-7
$
$       M1      M2      ETC                                             +MK
MKAERO1 2.0     3.0                                                     +MK
$       K1      K2      K3      ETC
+MK     0.001   0.1     0.2     0.4
$
FLUTTER 30      PK      1       2       3               4
FLFACT  1       0.5
FLFACT  2       2.0     3.0
FLFACT  3       21600.  22800.  23400.  24000.  26400.  28800.  29400.  +FL3
+FL3    30000.  31200.
$
PARAM   VREF    12.0
$                                               ND
EIGR    20      AGIV    0.      1000.           15                      +ER
+ER     MAX
$
$PARAM  LMODES  9
$
PARAM   OPPHIPA 1
$
ENDDATA
INPUT BULK DATA CARD COUNT =     216
```

Listing 8-31 Sorted Bulk Data for Flutter Analysis of Square Panel Using Piston Theory

```
 3D PANEL FLUTTER                                                                                                        PAGE     9
  PINNED EDGES
  PISTON THEORY AERO WITH VAN DYKE CORRECTION, EXAMPLE HA145HA
                                             S O R T E D   B U L K   D A T A   E C H O
             CARD
             COUNT        .  1  ..  2  ..  3  ..  4  ..  5  ..  6  ..  7  ..  8  ..  9  .. 10  .
                1-        AEFACT  10      0.0     0.0     0.0     0.0     0.0     0.0
                2-        AEFACT  20      2.0     0.0     3.0     0.0
                3-        AERO    0       0       10.0    1.1468-7
                4-        CAERO5  1001    1001            10              1       10              +CA501
                5-        +CA501  0.0     0.0     0.0     1.0     0.0     10.0    0.0     1.0
                6-        CAERO5  2001    1001            10              1       10              +CA502
                7-        +CA502  1.0     0.0     0.0     1.0     1.0     10.0    0.0     1.0
                8-        CAERO5  3001    1001            10              1       10              +CA503
                9-        +CA503  2.0     0.0     0.0     1.0     2.0     10.0    0.0     1.0
               10-        CAERO5  4001    1001            10              1       10              +CA504
               11-        +CA504  3.0     0.0     0.0     1.0     3.0     10.0    0.0     1.0
               12-        CAERO5  5001    1001            10              1       10              +CA505
               13-        +CA505  4.0     0.0     0.0     1.0     4.0     10.0    0.0     1.0
               14-        CAERO5  6001    1001            10              1       10              +CA506
               15-        +CA506  5.0     0.0     0.0     1.0     5.0     10.0    0.0     1.0
               16-        CAERO5  7001    1001            10              1       10              +CA507
               17-        +CA507  6.0     0.0     0.0     1.0     6.0     10.0    0.0     1.0
               18-        CAERO5  8001    1001            10              1       10              +CA508
               19-        +CA508  7.0     0.0     0.0     1.0     7.0     10.0    0.0     1.0
               20-        CAERO5  9001    1001            10              1       10              +CA509
               21-        +CA509  8.0     0.0     0.0     1.0     8.0     10.0    0.0     1.0
               22-        CAERO5  10001   1001            10              1       10              +CA510
               23-        +CA510  9.0     0.0     0.0     1.0     9.0     10.0    0.0     1.0
               24-        CORD2R  1               0.5     0.0     0.0     0.5     0.0     1.0     +CRD1
               25-        +CRD1   20.0    0.0     0.0
               26-        CORD2R  2               1.5     0.0     0.0     1.5     0.0     1.0     +CRD2
               27-        +CRD2   20.0    0.0     0.0
               28-        CORD2R  3               2.5     0.0     0.0     2.5     0.0     1.0     +CRD3
               29-        +CRD3   20.0    0.0     0.0
               30-        CORD2R  4               3.5     0.0     0.0     3.5     0.0     1.0     +CRD4
               31-        +CRD4   20.0    0.0     0.0
               32-        CORD2R  5               4.5     0.0     0.0     4.5     0.0     1.0     +CRD5
               33-        +CRD5   20.0    0.0     0.0
               34-        CORD2R  6               5.5     0.0     0.0     5.5     0.0     1.0     +CRD6
               35-        +CRD6   20.0    0.0     0.0
               36-        CORD2R  7               6.5     0.0     0.0     6.5     0.0     1.0     +CRD7
               37-        +CRD7   20.0    0.0     0.0
               38-        CORD2R  8               7.5     0.0     0.0     7.5     0.0     1.0     +CRD8
               39-        +CRD8   20.0    0.0     0.0
               40-        CORD2R  9               8.5     0.0     0.0     8.5     0.0     1.0     +CRD9
               41-        +CRD9   20.0    0.0     0.0
               42-        CORD2R  10              9.5     0.0     0.0     9.5     0.0     1.0     +CRD10
               43-        +CRD10  20.0    0.0     0.0
               44-        CQUAD4  1       1       1       2       13      12
               45-        CQUAD4  2       1       2       3       14      13
               46-        CQUAD4  3       1       3       4       15      14
               47-        CQUAD4  4       1       4       5       16      15
               48-        CQUAD4  5       1       5       6       17      16
               49-        CQUAD4  6       1       6       7       18      17
               50-        CQUAD4  7       1       7       8       19      18
               51-        CQUAD4  8       1       8       9       20      19
               52-        CQUAD4  9       1       9       10      21      20
               53-        CQUAD4  10      1       10      11      22      21
               54-        CQUAD4  11      1       12      13      24      23
               55-        CQUAD4  12      1       13      14      25      24
               56-        CQUAD4  13      1       14      15      26      25
               57-        CQUAD4  14      1       15      16      27      26
               58-        CQUAD4  15      1       16      17      28      27
               59-        CQUAD4  16      1       17      18      29      28
               60-        CQUAD4  17      1       18      19      30      29
               61-        CQUAD4  18      1       19      20      31      30
               62-        CQUAD4  19      1       20      21      32      31
               63-        CQUAD4  20      1       21      22      33      32
               64-        CQUAD4  21      1       23      24      35      34
               65-        CQUAD4  22      1       24      25      36      35
               66-        CQUAD4  23      1       25      26      37      36
               67-        CQUAD4  24      1       26      27      38      37
               68-        CQUAD4  25      1       27      28      39      38
               69-        CQUAD4  26      1       28      29      40      39
               70-        CQUAD4  27      1       29      30      41      40
               71-        CQUAD4  28      1       30      31      42      41
               72-        CQUAD4  29      1       31      32      43      42
               73-        CQUAD4  30      1       32      33      44      43
               74-        CQUAD4  31      1       34      35      46      45
               75-        CQUAD4  32      1       35      36      47      46
```

Listing 8-31 Sorted Bulk Data for Flutter Analysis of Square Panel Using Piston Theory (Continued)

```
   76-        CQUAD4  33      1       36      37      48      47
   77-        CQUAD4  34      1       37      38      49      48
   78-        CQUAD4  35      1       38      39      50      49
   79-        CQUAD4  36      1       39      40      51      50
   80-        CQUAD4  37      1       40      41      52      51
   81-        CQUAD4  38      1       41      42      53      52
   82-        CQUAD4  39      1       42      43      54      53
   83-        CQUAD4  40      1       43      44      55      54
   84-        CQUAD4  41      1       45      46      57      56
   85-        CQUAD4  42      1       46      47      58      57
   86-        CQUAD4  43      1       47      48      59      58
   87-        CQUAD4  44      1       48      49      60      59
   88-        CQUAD4  45      1       49      50      61      60
   89-        CQUAD4  46      1       50      51      62      61
   90-        CQUAD4  47      1       51      52      63      62
   91-        CQUAD4  48      1       52      53      64      63
   92-        CQUAD4  49      1       53      54      65      64
   93-        CQUAD4  50      1       54      55      66      65
   94-        CQUAD4  51      1       56      57      68      67
   95-        CQUAD4  52      1       57      58      69      68
   96-        CQUAD4  53      1       58      59      70      69
   97-        CQUAD4  54      1       59      60      71      70
   98-        CQUAD4  55      1       60      61      72      71
   99-        CQUAD4  56      1       61      62      73      72
  100-        CQUAD4  57      1       62      63      74      73
  101-        CQUAD4  58      1       63      64      75      74
  102-        CQUAD4  59      1       64      65      76      75
  103-        CQUAD4  60      1       65      66      77      76
  104-        CQUAD4  61      1       67      68      79      78
  105-        CQUAD4  62      1       68      69      80      79
  106-        CQUAD4  63      1       69      70      81      80
  107-        CQUAD4  64      1       70      71      82      81
  108-        CQUAD4  65      1       71      72      83      82
  109-        CQUAD4  66      1       72      73      84      83
  110-        CQUAD4  67      1       73      74      85      84
  111-        CQUAD4  68      1       74      75      86      85
  112-        CQUAD4  69      1       75      76      87      86
  113-        CQUAD4  70      1       76      77      88      87
  114-        CQUAD4  71      1       78      79      90      89
  115-        CQUAD4  72      1       79      80      91      90
  116-        CQUAD4  73      1       80      81      92      91
  117-        CQUAD4  74      1       81      82      93      92
  118-        CQUAD4  75      1       82      83      94      93
  119-        CQUAD4  76      1       83      84      95      94
  120-        CQUAD4  77      1       84      85      96      95
  121-        CQUAD4  78      1       85      86      97      96
  122-        CQUAD4  79      1       86      87      98      97
  123-        CQUAD4  80      1       87      88      99      98
  124-        CQUAD4  81      1       89      90      101     100
  125-        CQUAD4  82      1       90      91      102     101
  126-        CQUAD4  83      1       91      92      103     102
  127-        CQUAD4  84      1       92      93      104     103
  128-        CQUAD4  85      1       93      94      105     104
  129-        CQUAD4  86      1       94      95      106     105
  130-        CQUAD4  87      1       95      96      107     106
  131-        CQUAD4  88      1       96      97      108     107
  132-        CQUAD4  89      1       97      98      109     108
  133-        CQUAD4  90      1       98      99      110     109
  134-        CQUAD4  91      1       100     101     112     111
  135-        CQUAD4  92      1       101     102     113     112
  136-        CQUAD4  93      1       102     103     114     113
  137-        CQUAD4  94      1       103     104     115     114
  138-        CQUAD4  95      1       104     105     116     115
  139-        CQUAD4  96      1       105     106     117     116
  140-        CQUAD4  97      1       106     107     118     117
  141-        CQUAD4  98      1       107     108     119     118
  142-        CQUAD4  99      1       108     109     120     119
  143-        CQUAD4  100     1       109     110     121     120
  144-        EIGR    20      AGIV    0.      1000.           15                      +ER
  145-        +ER     MAX
  146-        FLFACT  1       0.5
  147-        FLFACT  2       2.0     3.0
  148-        FLFACT  3       21600.  22800.  23400.  24000.  26400.  28800.  29400.  +FL3
  149-        +FL3    30000.  31200.
  150-        FLUTTER 30      PK      1       2       3               4
  151-        GRID    1               0.0     0.0     0.0
  152-        GRID    2               0.0     1.0     0.0
  153-        GRID    3               0.0     2.      0.0
  154-        GRID    4               0.0     3.      0.0
  155-        GRID    5               0.0     4.      0.0
  156-        GRID    6               0.0     5.      0.0
  157-        GRID    7               0.0     6.      0.0
  158-        GRID    8               0.0     7.      0.0
```

Listing 8-31 Sorted Bulk Data for Flutter Analysis of Square Panel Using Piston Theory (Continued)

```
159-        GRID    9               0.0     8.      0.0
160-        GRID    10              0.0     9.      0.0
161-        GRID    11              0.0     10.     0.0
162-        GRID    12              1.0     0.0     0.0
163-        GRID    13              1.0     1.0     0.0
164-        GRID    14              1.0     2.      0.0
165-        GRID    15              1.0     3.      0.0
166-        GRID    16              1.0     4.      0.0
167-        GRID    17              1.0     5.      0.0
168-        GRID    18              1.0     6.      0.0
169-        GRID    19              1.0     7.      0.0
170-        GRID    20              1.0     8.      0.0
171-        GRID    21              1.0     9.      0.0
172-        GRID    22              1.0     10.     0.0
173-        GRID    23              2.0     0.0     0.0
174-        GRID    24              2.0     1.0     0.0
175-        GRID    25              2.0     2.      0.0
176-        GRID    26              2.0     3.      0.0
177-        GRID    27              2.0     4.      0.0
178-        GRID    28              2.0     5.      0.0
179-        GRID    29              2.0     6.      0.0
180-        GRID    30              2.0     7.      0.0
181-        GRID    31              2.0     8.      0.0
182-        GRID    32              2.0     9.      0.0
183-        GRID    33              2.0     10.     0.0
184-        GRID    34              3.0     0.0     0.0
185-        GRID    35              3.0     1.0     0.0
186-        GRID    36              3.0     2.      0.0
187-        GRID    37              3.0     3.      0.0
188-        GRID    38              3.0     4.      0.0
189-        GRID    39              3.0     5.      0.0
190-        GRID    40              3.0     6.      0.0
191-        GRID    41              3.0     7.      0.0
192-        GRID    42              3.0     8.      0.0
193-        GRID    43              3.0     9.      0.0
194-        GRID    44              3.0     10.     0.0
195-        GRID    45              4.0     0.0     0.0
196-        GRID    46              4.0     1.0     0.0
197-        GRID    47              4.0     2.      0.0
198-        GRID    48              4.0     3.      0.0
199-        GRID    49              4.0     4.      0.0
200-        GRID    50              4.0     5.      0.0
201-        GRID    51              4.0     6.      0.0
202-        GRID    52              4.0     7.      0.0
203-        GRID    53              4.0     8.      0.0
204-        GRID    54              4.0     9.      0.0
205-        GRID    55              4.0     10.     0.0
206-        GRID    56              5.0     0.0     0.0
207-        GRID    57              5.0     1.0     0.0
208-        GRID    58              5.0     2.      0.0
209-        GRID    59              5.0     3.      0.0
210-        GRID    60              5.0     4.      0.0
211-        GRID    61              5.0     5.      0.0
212-        GRID    62              5.0     6.      0.0
213-        GRID    63              5.0     7.      0.0
214-        GRID    64              5.0     8.      0.0
215-        GRID    65              5.0     9.      0.0
216-        GRID    66              5.0     10.     0.0
217-        GRID    67              6.0     0.0     0.0
218-        GRID    68              6.0     1.0     0.0
219-        GRID    69              6.0     2.      0.0
220-        GRID    70              6.0     3.      0.0
221-        GRID    71              6.0     4.      0.0
222-        GRID    72              6.0     5.      0.0
223-        GRID    73              6.0     6.      0.0
224-        GRID    74              6.0     7.      0.0
225-        GRID    75              6.0     8.      0.0
226-        GRID    76              6.0     9.      0.0
227-        GRID    77              6.0     10.     0.0
228-        GRID    78              7.0     0.0     0.0
229-        GRID    79              7.0     1.0     0.0
230-        GRID    80              7.0     2.      0.0
231-        GRID    81              7.0     3.      0.0
232-        GRID    82              7.0     4.      0.0
233-        GRID    83              7.0     5.      0.0
234-        GRID    84              7.0     6.      0.0
235-        GRID    85              7.0     7.      0.0
236-        GRID    86              7.0     8.      0.0
237-        GRID    87              7.0     9.      0.0
238-        GRID    88              7.0     10.     0.0
239-        GRID    89              8.0     0.0     0.0
240-        GRID    90              8.0     1.0     0.0
```

Listing 8-31 Sorted Bulk Data for Flutter Analysis of Square Panel Using Piston Theory (Continued)

```
241-        GRID    91              8.0     2.      0.0
242-        GRID    92              8.0     3.      0.0
243-        GRID    93              8.0     4.      0.0
244-        GRID    94              8.0     5.      0.0
245-        GRID    95              8.0     6.      0.0
246-        GRID    96              8.0     7.      0.0
247-        GRID    97              8.0     8.      0.0
248-        GRID    98              8.0     9.      0.0
249-        GRID    99              8.0     10.     0.0
250-        GRID    100             9.0     0.0     0.0
251-        GRID    101             9.0     1.0     0.0
252-        GRID    102             9.0     2.      0.0
253-        GRID    103             9.0     3.      0.0
254-        GRID    104             9.0     4.      0.0
255-        GRID    105             9.0     5.      0.0
256-        GRID    106             9.0     6.      0.0
257-        GRID    107             9.0     7.      0.0
258-        GRID    108             9.0     8.      0.0
259-        GRID    109             9.0     9.      0.0
260-        GRID    110             9.0     10.     0.0
261-        GRID    111             10.0    0.0     0.0
262-        GRID    112             10.0    1.0     0.0
263-        GRID    113             10.0    2.      0.0
264-        GRID    114             10.0    3.      0.0
265-        GRID    115             10.0    4.      0.0
266-        GRID    116             10.0    5.      0.0
267-        GRID    117             10.0    6.      0.0
268-        GRID    118             10.0    7.      0.0
269-        GRID    119             10.0    8.      0.0
270-        GRID    120             10.0    9.      0.0
271-        GRID    121             10.0    10.     0.0
272-        MAT1    10      1.03+7  3.9+6           .1
273-        MKAERO1 2.0     3.0                                                     +MK
274-        +MK     0.001   0.1     0.2     0.4
275-        PAERO5  1001    1       20                                              +PA5
276-        +PA5    0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     +PA51
277-        +PA51   0.0     0.0
278-        PARAM   COUPMASS1
279-        PARAM   GRDPNT  1
280-        PARAM   OPPHIPA 1
281-        PARAM   VREF    12.0
282-        PARAM   WTMASS  .0025907
283-        PSHELL  1       10      .041    10
284-        SET1    1001    1       THRU    22
285-        SET1    2001    12      THRU    33
286-        SET1    3001    23      THRU    44
287-        SET1    4001    34      THRU    55
288-        SET1    5001    45      THRU    66
289-        SET1    6001    56      THRU    77
290-        SET1    7001    67      THRU    88
291-        SET1    8001    78      THRU    99
292-        SET1    9001    89      THRU    110
293-        SET1    10001   100     THRU    121
294-        SPC1    1       1       1
295-        SPC1    1       2       1       110
296-        SPC1    1       3       1       THRU    11
297-        SPC1    1       3       12      22      23      33      34      44      +SP1
298-        +SP1    45      55      56      66      67      77      78      88      +SP2
299-        +SP2    89      99      100     110
300-        SPC1    1       3       111     THRU    121
301-        SPC1    1       6       1       THRU    121
302-        SPLINE2 1001    1001    1001    1010    1001    0.0     1.0     1       +SPL1
303-        +SPL1   -1.0    -1.0
304-        SPLINE2 2001    2001    2001    2010    2001    0.0     1.0     2       +SPL2
305-        +SPL2   -1.0    -1.0
306-        SPLINE2 3001    3001    3001    3010    3001    0.0     1.0     3       +SPL3
307-        +SPL3   -1.0    -1.0
308-        SPLINE2 4001    4001    4001    4010    4001    0.0     1.0     4       +SPL4
309-        +SPL4   -1.0    -1.0
310-        SPLINE2 5001    5001    5001    5010    5001    0.0     1.0     5       +SPL5
311-        +SPL5   -1.0    -1.0
312-        SPLINE2 6001    6001    6001    6010    6001    0.0     1.0     6       +SPL6
313-        +SPL6   -1.0    -1.0
314-        SPLINE2 7001    7001    7001    7010    7001    0.0     1.0     7       +SPL7
315-        +SPL7   -1.0    -1.0
316-        SPLINE2 8001    8001    8001    8010    8001    0.0     1.0     8       +SPL8
317-        +SPL8   -1.0    -1.0
318-        SPLINE2 9001    9001    9001    9010    9001    0.0     1.0     9       +SPL9
319-        +SPL9   -1.0    -1.0
320-        SPLINE2 10001   10001   10001   10010   10001   0.0     1.0     10      +SPL10
321-        +SPL10  -1.0    -1.0
            ENDDATA
      TOTAL COUNT=      322
```

Listing 8-32 Output for Flutter Analysis of Square Panel Using Piston Theory

```
3D PANEL FLUTTER                                                                                              PAGE    19
  PINNED EDGES
 PISTON THEORY AERO WITH VAN DYKE CORRECTION, EXAMPLE HA145HA
                                   O U T P U T   F R O M   G R I D   P O I N T   W E I G H T   G E N E R A T O R

                                                       REFERENCE POINT =         1
                                                                 M O
                  *  4.100000E-01  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00 -2.050000E+00 *
                  *  0.000000E+00  4.100000E-01  0.000000E+00  0.000000E+00  0.000000E+00  2.050000E+00 *
                  *  0.000000E+00  0.000000E+00  4.100000E-01  2.050000E+00 -2.050000E+00  0.000000E+00 *
                  *  0.000000E+00  0.000000E+00  2.050000E+00  1.366667E+01 -1.025000E+01  0.000000E+00 *
                  *  0.000000E+00  0.000000E+00 -2.050000E+00 -1.025000E+01  1.366667E+01  0.000000E+00 *
                  * -2.050000E+00  2.050000E+00  0.000000E+00  0.000000E+00  0.000000E+00  2.733333E+01 *
                                                                  S
                                     *  1.000000E+00  0.000000E+00  0.000000E+00 *
                                     *  0.000000E+00  1.000000E+00  0.000000E+00 *
                                     *  0.000000E+00  0.000000E+00  1.000000E+00 *

                     DIRECTION
                 MASS AXIS SYSTEM (S)      MASS            X-C.G.        Y-C.G.        Z-C.G.
                         X            4.100000E-01      0.000000E+00  5.000000E+00  0.000000E+00
                         Y            4.100000E-01      5.000000E+00  0.000000E+00  0.000000E+00
                         Z            4.100000E-01      5.000000E+00  5.000000E+00  0.000000E+00
                                                                 I(S)
                                     *  3.416665E+00 -1.907349E-06  0.000000E+00 *
                                     * -1.907349E-06  3.416665E+00  0.000000E+00 *
                                     *  0.000000E+00  0.000000E+00  6.833330E+00 *
                                                                 I(Q)
                                     *  3.416665E+00                             *
                                     *                3.416665E+00               *
                                     *                              6.833330E+00 *
                                                                  Q
                                     *  1.000000E+00  0.000000E+00  0.000000E+00 *
                                     *  0.000000E+00  1.000000E+00  0.000000E+00 *
                                     *  0.000000E+00  0.000000E+00  1.000000E+00 *

                                        R E A L   E I G E N V A L U E S

 MODE    EXTRACTION      EIGENVALUE            RADIANS             CYCLES            GENERALIZED         GENERALIZED
  NO.       ORDER                                                                        MASS              STIFFNESS
     1        303        2.437391E+05        4.936994E+02        7.857470E+01        2.569396E-04        6.262624E+01
     2        318        1.585938E+06        1.259340E+03        2.004302E+02        2.385697E-04        3.783567E+02
     3        317        1.585938E+06        1.259340E+03        2.004302E+02        2.385697E-04        3.783567E+02
     4        304        4.074306E+06        2.018491E+03        3.212528E+02        2.844406E-04        1.158898E+03
     5        309        6.896249E+06        2.626071E+03        4.179522E+02        1.134159E-04        7.821444E+02
     6        310        6.896309E+06        2.626083E+03        4.179540E+02        1.902268E-04        1.311863E+03
     7        319        1.147131E+07        3.386933E+03        5.390471E+02        1.608912E-04        1.845633E+03
     8        308        1.147131E+07        3.386933E+03        5.390471E+02        1.608912E-04        1.845633E+03
     9        320        2.243252E+07        4.736298E+03        7.538052E+02        2.058151E-04        4.616952E+03
    10        313        2.243252E+07        4.736298E+03        7.538052E+02        2.058151E-04        4.616952E+03
    11        307        2.257317E+07        4.751123E+03        7.561647E+02        1.957289E-04        4.418221E+03
    12        305        3.065322E+07        5.536535E+03        8.811669E+02        2.404108E-04        7.369367E+03
    13        306        3.065704E+07        5.536880E+03        8.812218E+02        2.445093E-04        7.495932E+03
    14        302        4.779749E+07        6.913573E+03        1.100329E+03        1.659348E-04        7.931270E+03
    15        316        4.779749E+07        6.913573E+03        1.100329E+03        1.659348E-04        7.931270E+03
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Listing 8-32 Output for Flutter Analysis of Square Panel Using Piston Theory (Continued)

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EIGENVALUE =  2.437391E+05
    CYCLES =  7.857470E+01        R E A L   E I G E N V E C T O R   N O .          1

POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
       1      G      0.0            0.0            0.0            8.264631E-04  -8.264631E-04   0.0
       2      G      0.0            0.0            0.0            7.895400E-04  -9.712248E-02   0.0
       3      G      0.0            0.0            0.0            6.727834E-04  -1.841179E-01   0.0
       4      G      0.0            0.0            0.0            4.893358E-04  -2.532092E-01   0.0
       5      G      0.0            0.0            0.0            2.573338E-04  -2.975848E-01   0.0
       6      G      0.0            0.0            0.0            2.115821E-15  -3.128780E-01   0.0
       7      G      0.0            0.0            0.0           -2.573338E-04  -2.975848E-01   0.0
       8      G      0.0            0.0            0.0           -4.893358E-04  -2.532092E-01   0.0
       9      G      0.0            0.0            0.0           -6.727834E-04  -1.841179E-01   0.0
      10      G      0.0            0.0            0.0           -7.895400E-04  -9.712248E-02   0.0
      11      G      0.0            0.0            0.0           -8.264631E-04  -8.264631E-04   0.0
      12      G      0.0            0.0            0.0            9.712248E-02  -7.895400E-04   0.0
      13      G      0.0            0.0            9.547547E-02   9.238406E-02  -9.238406E-02   0.0
      14      G      0.0            0.0            1.816133E-01   7.859124E-02  -1.751367E-01   0.0
      15      G      0.0            0.0            2.499747E-01   5.710068E-02  -2.408578E-01   0.0
      16      G      0.0            0.0            2.938657E-01   3.001965E-02  -2.830689E-01   0.0
      17      G      0.0            0.0            3.089895E-01  -4.522600E-14  -2.976160E-01   0.0
      18      G      0.0            0.0            2.938657E-01  -3.001965E-02  -2.830689E-01   0.0
      19      G      0.0            0.0            2.499747E-01  -5.710068E-02  -2.408578E-01   0.0
      20      G      0.0            0.0            1.816133E-01  -7.859124E-02  -1.751367E-01   0.0
      21      G      0.0            0.0            9.547547E-02  -9.238406E-02  -9.238406E-02   0.0
      22      G      0.0            0.0            0.0           -9.712248E-02  -7.895400E-04   0.0
      23      G      0.0            0.0            0.0            1.841179E-01  -6.727834E-04   0.0
      24      G      0.0            0.0            1.816133E-01   1.751367E-01  -7.859124E-02   0.0
      25      G      0.0            0.0            3.454662E-01   1.489877E-01  -1.489877E-01   0.0
      26      G      0.0            0.0            4.755045E-01   1.082471E-01  -2.048963E-01   0.0
      27      G      0.0            0.0            5.589946E-01   5.690884E-02  -2.408050E-01   0.0
      28      G      0.0            0.0            5.877633E-01  -8.636837E-14  -2.531802E-01   0.0
      29      G      0.0            0.0            5.589946E-01  -5.690884E-02  -2.408050E-01   0.0
      30      G      0.0            0.0            4.755045E-01  -1.082471E-01  -2.048963E-01   0.0
      31      G      0.0            0.0            3.454662E-01  -1.489877E-01  -1.489877E-01   0.0
      32      G      0.0            0.0            1.816133E-01  -1.751367E-01  -7.859124E-02   0.0
      33      G      0.0            0.0            0.0           -1.841179E-01  -6.727834E-04   0.0
      34      G      0.0            0.0            0.0            2.532092E-01  -4.893358E-04   0.0
      35      G      0.0            0.0            2.499747E-01   2.408578E-01  -5.710068E-02   0.0
      36      G      0.0            0.0            4.755045E-01   2.048963E-01  -1.082471E-01   0.0
      37      G      0.0            0.0            6.544914E-01   1.488674E-01  -1.488674E-01   0.0
      38      G      0.0            0.0            7.694086E-01   7.826415E-02  -1.749569E-01   0.0
      39      G      0.0            0.0            8.090063E-01  -1.219637E-13  -1.839480E-01   0.0
      40      G      0.0            0.0            7.694086E-01  -7.826415E-02  -1.749569E-01   0.0
      41      G      0.0            0.0            6.544914E-01  -1.488674E-01  -1.488674E-01   0.0
      42      G      0.0            0.0            4.755045E-01  -2.048963E-01  -1.082471E-01   0.0
      43      G      0.0            0.0            2.499747E-01  -2.408578E-01  -5.710068E-02   0.0
      44      G      0.0            0.0            0.0           -2.532092E-01  -4.893358E-04   0.0
      45      G      0.0            0.0            0.0            2.975848E-01  -2.573338E-04   0.0
      46      G      0.0            0.0            2.938657E-01   2.830689E-01  -3.001965E-02   0.0
      47      G      0.0            0.0            5.589946E-01   2.408050E-01  -5.690884E-02   0.0
      48      G      0.0            0.0            7.694086E-01   1.749569E-01  -7.826415E-02   0.0
      49      G      0.0            0.0            9.045033E-01   9.198016E-02  -9.198016E-02   0.0
      50      G      0.0            0.0            9.510538E-01  -1.531339E-13  -9.670710E-02   0.0
      51      G      0.0            0.0            9.045033E-01  -9.198016E-02  -9.198016E-02   0.0
      52      G      0.0            0.0            7.694086E-01  -1.749569E-01  -7.826415E-02   0.0
      53      G      0.0            0.0            5.589946E-01  -2.408050E-01  -5.690884E-02   0.0
      54      G      0.0            0.0            2.938657E-01  -2.830689E-01  -3.001965E-02   0.0
      55      G      0.0            0.0            0.0           -2.975848E-01  -2.573338E-04   0.0
      56      G      0.0            0.0            0.0            3.128780E-01   4.657190E-16   0.0
      57      G      0.0            0.0            3.089895E-01   2.976160E-01  -2.972403E-14   0.0
      58      G      0.0            0.0            5.877633E-01   2.531802E-01  -5.555368E-14   0.0
      59      G      0.0            0.0            8.090063E-01   1.839480E-01  -6.635859E-14   0.0
      60      G      0.0            0.0            9.510538E-01   9.670710E-02  -6.528196E-14   0.0
      61      G      0.0            0.0            1.000000E+00  -1.692418E-13  -5.969057E-14   0.0
      62      G      0.0            0.0            9.510538E-01  -9.670710E-02  -4.617972E-14   0.0
      63      G      0.0            0.0            8.090063E-01  -1.839480E-01  -3.487857E-14   0.0
      64      G      0.0            0.0            5.877633E-01  -2.531802E-01  -3.507687E-14   0.0
      65      G      0.0            0.0            3.089895E-01  -2.976160E-01  -2.423626E-14   0.0
      66      G      0.0            0.0            0.0           -3.128780E-01  -7.589415E-17   0.0
      67      G      0.0            0.0            0.0            2.975848E-01   2.573338E-04   0.0
      68      G      0.0            0.0            2.938657E-01   2.830689E-01   3.001965E-02   0.0
      69      G      0.0            0.0            5.589946E-01   2.408050E-01   5.690884E-02   0.0
      70      G      0.0            0.0            7.694086E-01   1.749569E-01   7.826415E-02   0.0
      71      G      0.0            0.0            9.045033E-01   9.198016E-02   9.198016E-02   0.0
      72      G      0.0            0.0            9.510538E-01  -1.703268E-13   9.670710E-02   0.0
      73      G      0.0            0.0            9.045033E-01  -9.198016E-02   9.198016E-02   0.0
      74      G      0.0            0.0            7.694086E-01  -1.749569E-01   7.826415E-02   0.0
      75      G      0.0            0.0            5.589946E-01  -2.408050E-01   5.690884E-02   0.0
      76      G      0.0            0.0            2.938657E-01  -2.830689E-01   3.001965E-02   0.0
      77      G      0.0            0.0            0.0           -2.975848E-01   2.573338E-04   0.0
      78      G      0.0            0.0            0.0            2.532092E-01   4.893358E-04   0.0
      79      G      0.0            0.0            2.499747E-01   2.408578E-01   5.710068E-02   0.0
      80      G      0.0            0.0            4.755045E-01   2.048963E-01   1.082471E-01   0.0
      81      G      0.0            0.0            6.544914E-01   1.488674E-01   1.488674E-01   0.0
      82      G      0.0            0.0            7.694086E-01   7.826415E-02   1.749569E-01   0.0
      83      G      0.0            0.0            8.090063E-01  -1.458745E-13   1.839480E-01   0.0
      84      G      0.0            0.0            7.694086E-01  -7.826415E-02   1.749569E-01   0.0
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Listing 8-32 Output for Flutter Analysis of Square Panel Using Piston Theory (Continued)

85	G	0.0	0.0	6.544914E-01	-1.488674E-01	1.488674E-01	0.0
86	G	0.0	0.0	4.755045E-01	-2.048963E-01	1.082471E-01	0.0
87	G	0.0	0.0	2.499747E-01	-2.408578E-01	5.710068E-02	0.0
88	G	0.0	0.0	0.0	-2.532092E-01	4.893358E-04	0.0
89	G	0.0	0.0	0.0	1.841179E-01	6.727834E-04	0.0
90	G	0.0	0.0	1.816133E-01	1.751367E-01	7.859124E-02	0.0
91	G	0.0	0.0	3.454662E-01	1.489877E-01	1.489877E-01	0.0
92	G	0.0	0.0	4.755045E-01	1.082471E-01	2.048963E-01	0.0
93	G	0.0	0.0	5.589946E-01	5.690884E-02	2.408050E-01	0.0
94	G	0.0	0.0	5.877633E-01	-9.868105E-14	2.531802E-01	0.0
95	G	0.0	0.0	5.589946E-01	-5.690884E-02	2.408050E-01	0.0
96	G	0.0	0.0	4.755045E-01	-1.082471E-01	2.048963E-01	0.0
97	G	0.0	0.0	3.454662E-01	-1.489877E-01	1.489877E-01	0.0
98	G	0.0	0.0	1.816133E-01	-1.751367E-01	7.859124E-02	0.0
99	G	0.0	0.0	0.0	-1.841179E-01	6.727834E-04	0.0
100	G	0.0	0.0	0.0	9.712248E-02	7.895400E-04	0.0
101	G	0.0	0.0	9.547547E-02	9.238406E-02	9.238406E-02	0.0
102	G	0.0	0.0	1.816133E-01	7.859124E-02	1.751367E-01	0.0
103	G	0.0	0.0	2.499747E-01	5.710068E-02	2.408578E-01	0.0
104	G	0.0	0.0	2.938657E-01	3.001965E-02	2.830689E-01	0.0
105	G	0.0	0.0	3.089895E-01	-4.968942E-14	2.976160E-01	0.0
106	G	0.0	0.0	2.938657E-01	-3.001965E-02	2.830689E-01	0.0
107	G	0.0	0.0	2.499747E-01	-5.710068E-02	2.408578E-01	0.0
108	G	0.0	0.0	1.816133E-01	-7.859124E-02	1.751367E-01	0.0
109	G	0.0	0.0	9.547547E-02	-9.238406E-02	9.238406E-02	0.0
110	G	0.0	0.0	0.0	-9.712248E-02	7.895400E-04	0.0
111	G	0.0	0.0	0.0	8.264631E-04	8.264631E-04	0.0
112	G	0.0	0.0	0.0	7.895400E-04	9.712248E-02	0.0
113	G	0.0	0.0	0.0	6.727834E-04	1.841179E-01	0.0
114	G	0.0	0.0	0.0	4.893358E-04	2.532092E-01	0.0
115	G	0.0	0.0	0.0	2.573338E-04	2.975848E-01	0.0
116	G	0.0	0.0	0.0	3.291204E-15	3.128780E-01	0.0
117	G	0.0	0.0	0.0	-2.573338E-04	2.975848E-01	0.0
118	G	0.0	0.0	0.0	-4.893358E-04	2.532092E-01	0.0
119	G	0.0	0.0	0.0	-6.727834E-04	1.841179E-01	0.0
120	G	0.0	0.0	0.0	-7.895400E-04	9.712248E-02	0.0
121	G	0.0	0.0	0.0	-8.264631E-04	8.264631E-04	0.0
1001	G	0.0	0.0	1.223094E-02	0.0	-4.773773E-02	0.0
1002	G	0.0	0.0	3.549739E-02	0.0	-1.385444E-01	0.0
1003	G	0.0	0.0	5.529068E-02	0.0	-2.157940E-01	0.0
1004	G	0.0	0.0	6.967133E-02	0.0	-2.719202E-01	0.0
1005	G	0.0	0.0	7.723170E-02	0.0	-3.014276E-01	0.0
1006	G	0.0	0.0	7.723170E-02	0.0	-3.014276E-01	0.0
1007	G	0.0	0.0	6.967132E-02	0.0	-2.719202E-01	0.0
1008	G	0.0	0.0	5.529068E-02	0.0	-2.157940E-01	0.0
1009	G	0.0	0.0	3.549739E-02	0.0	-1.385444E-01	0.0
1010	G	0.0	0.0	1.223094E-02	0.0	-4.773773E-02	0.0
2001	G	0.0	0.0	5.936538E-02	0.0	-4.306890E-02	0.0
2002	G	0.0	0.0	1.722928E-01	0.0	-1.249954E-01	0.0
2003	G	0.0	0.0	2.683622E-01	0.0	-1.946914E-01	0.0
2004	G	0.0	0.0	3.381610E-01	0.0	-2.453294E-01	0.0
2005	G	0.0	0.0	3.748565E-01	0.0	-2.719514E-01	0.0
2006	G	0.0	0.0	3.748565E-01	0.0	-2.719514E-01	0.0
2007	G	0.0	0.0	3.381609E-01	0.0	-2.453293E-01	0.0
2008	G	0.0	0.0	2.683622E-01	0.0	-1.946913E-01	0.0
2009	G	0.0	0.0	1.722928E-01	0.0	-1.249954E-01	0.0
2010	G	0.0	0.0	5.936538E-02	0.0	-4.306890E-02	0.0
3001	G	0.0	0.0	1.006919E-01	0.0	-3.418072E-02	0.0
3002	G	0.0	0.0	2.922330E-01	0.0	-9.919986E-02	0.0
3003	G	0.0	0.0	4.551809E-01	0.0	-1.545126E-01	0.0
3004	G	0.0	0.0	5.735700E-01	0.0	-1.947004E-01	0.0
3005	G	0.0	0.0	6.358110E-01	0.0	-2.158285E-01	0.0
3006	G	0.0	0.0	6.358110E-01	0.0	-2.158285E-01	0.0
3007	G	0.0	0.0	5.735699E-01	0.0	-1.947004E-01	0.0
3008	G	0.0	0.0	4.551808E-01	0.0	-1.545126E-01	0.0
3009	G	0.0	0.0	2.922330E-01	0.0	-9.919986E-02	0.0
3010	G	0.0	0.0	1.006919E-01	0.0	-3.418072E-02	0.0
4001	G	0.0	0.0	1.321623E-01	0.0	-2.194549E-02	0.0
4002	G	0.0	0.0	3.835681E-01	0.0	-6.369055E-02	0.0
4003	G	0.0	0.0	5.974443E-01	0.0	-9.920368E-02	0.0
4004	G	0.0	0.0	7.528353E-01	0.0	-1.250060E-01	0.0
4005	G	0.0	0.0	8.345295E-01	0.0	-1.385711E-01	0.0
4006	G	0.0	0.0	8.345295E-01	0.0	-1.385711E-01	0.0
4007	G	0.0	0.0	7.528352E-01	0.0	-1.250060E-01	0.0
4008	G	0.0	0.0	5.974442E-01	0.0	-9.920368E-02	0.0
4009	G	0.0	0.0	3.835681E-01	0.0	-6.369055E-02	0.0
4010	G	0.0	0.0	1.321623E-01	0.0	-2.194549E-02	0.0

Listing 8-32 Output for Flutter Analysis of Square Panel Using Piston Theory (Continued)

```
      5001      G      0.0            0.0            1.506951E-01   0.0            -7.561900E-03   0.0
      5002      G      0.0            0.0            4.373549E-01   0.0            -2.194626E-02   0.0
      5003      G      0.0            0.0            6.812225E-01   0.0            -3.418324E-02   0.0
      5004      G      0.0            0.0            8.584037E-01   0.0            -4.307410E-02   0.0
      5005      G      0.0            0.0            9.515538E-01   0.0            -4.774832E-02   0.0
      5006      G      0.0            0.0            9.515538E-01   0.0            -4.774832E-02   0.0
      5007      G      0.0            0.0            8.584037E-01   0.0            -4.307409E-02   0.0
      5008      G      0.0            0.0            6.812224E-01   0.0            -3.418323E-02   0.0
      5009      G      0.0            0.0            4.373549E-01   0.0            -2.194626E-02   0.0
      5010      G      0.0            0.0            1.506951E-01   0.0            -7.561900E-03   0.0
      6001      G      0.0            0.0            1.544761E-01   0.0             7.561900E-03   0.0
      6002      G      0.0            0.0            4.483280E-01   0.0             2.194626E-02   0.0
      6003      G      0.0            0.0            6.983141E-01   0.0             3.418324E-02   0.0
      6004      G      0.0            0.0            8.799408E-01   0.0             4.307410E-02   0.0
      6005      G      0.0            0.0            9.754279E-01   0.0             4.774832E-02   0.0
      6006      G      0.0            0.0            9.754279E-01   0.0             4.774832E-02   0.0
      6007      G      0.0            0.0            8.799407E-01   0.0             4.307409E-02   0.0
      6008      G      0.0            0.0            6.983141E-01   0.0             3.418323E-02   0.0
      6009      G      0.0            0.0            4.483280E-01   0.0             2.194626E-02   0.0
      6010      G      0.0            0.0            1.544761E-01   0.0             7.561900E-03   0.0
      7001      G      0.0            0.0            1.431350E-01   0.0             2.194549E-02   0.0
      7002      G      0.0            0.0            4.154134E-01   0.0             6.369055E-02   0.0
      7003      G      0.0            0.0            6.470461E-01   0.0             9.920368E-02   0.0
      7004      G      0.0            0.0            8.153383E-01   0.0             1.250060E-01   0.0
      7005      G      0.0            0.0            9.038150E-01   0.0             1.385711E-01   0.0
      7006      G      0.0            0.0            9.038150E-01   0.0             1.385711E-01   0.0
      7007      G      0.0            0.0            8.153383E-01   0.0             1.250060E-01   0.0
      7008      G      0.0            0.0            6.470461E-01   0.0             9.920368E-02   0.0
      7009      G      0.0            0.0            4.154134E-01   0.0             6.369055E-02   0.0
      7010      G      0.0            0.0            1.431350E-01   0.0             2.194549E-02   0.0
      8001      G      0.0            0.0            1.177823E-01   0.0             3.418072E-02   0.0
      8002      G      0.0            0.0            3.418329E-01   0.0             9.919986E-02   0.0
      8003      G      0.0            0.0            5.324371E-01   0.0             1.545126E-01   0.0
      8004      G      0.0            0.0            6.709202E-01   0.0             1.947004E-01   0.0
      8005      G      0.0            0.0            7.437253E-01   0.0             2.158285E-01   0.0
      8006      G      0.0            0.0            7.437253E-01   0.0             2.158285E-01   0.0
      8007      G      0.0            0.0            6.709201E-01   0.0             1.947004E-01   0.0
      8008      G      0.0            0.0            5.324371E-01   0.0             1.545126E-01   0.0
      8009      G      0.0            0.0            3.418329E-01   0.0             9.919986E-02   0.0
      8010      G      0.0            0.0            1.177823E-01   0.0             3.418072E-02   0.0
      9001      G      0.0            0.0            8.089983E-02   0.0             4.306890E-02   0.0
      9002      G      0.0            0.0            2.347905E-01   0.0             1.249954E-01   0.0
      9003      G      0.0            0.0            3.657078E-01   0.0             1.946914E-01   0.0
      9004      G      0.0            0.0            4.608257E-01   0.0             2.453294E-01   0.0
      9005      G      0.0            0.0            5.108322E-01   0.0             2.719514E-01   0.0
      9006      G      0.0            0.0            5.108322E-01   0.0             2.719514E-01   0.0
      9007      G      0.0            0.0            4.608256E-01   0.0             2.453293E-01   0.0
      9008      G      0.0            0.0            3.657078E-01   0.0             1.946913E-01   0.0
      9009      G      0.0            0.0            2.347905E-01   0.0             1.249954E-01   0.0
      9010      G      0.0            0.0            8.089983E-02   0.0             4.306890E-02   0.0
     10001      G      0.0            0.0            3.609981E-02   0.0             4.773773E-02   0.0
     10002      G      0.0            0.0            1.047696E-01   0.0             1.385444E-01   0.0
     10003      G      0.0            0.0            1.631877E-01   0.0             2.157940E-01   0.0
     10004      G      0.0            0.0            2.056314E-01   0.0             2.719202E-01   0.0
     10005      G      0.0            0.0            2.279455E-01   0.0             3.014276E-01   0.0
     10006      G      0.0            0.0            2.279455E-01   0.0             3.014276E-01   0.0
     10007      G      0.0            0.0            2.056314E-01   0.0             2.719202E-01   0.0
     10008      G      0.0            0.0            1.631877E-01   0.0             2.157940E-01   0.0
     10009      G      0.0            0.0            1.047696E-01   0.0             1.385444E-01   0.0
     10010      G      0.0            0.0            3.609981E-02   0.0             4.773773E-02   0.0
```

Listing 8-32 Output for Flutter Analysis of Square Panel Using Piston Theory (Continued)

```
EIGENVALUE =  1.585938E+06
    CYCLES =  2.004302E+02         R E A L   E I G E N V E C T O R   N O .         2

POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
       1      G      0.0            0.0            0.0           -2.427032E-03   4.922156E-03   0.0
       2      G      0.0            0.0            0.0           -2.042162E-03  -2.448997E-01   0.0
       3      G      0.0            0.0            0.0           -9.125334E-04  -4.484198E-01   0.0
       4      G      0.0            0.0            0.0            4.719342E-04  -5.735155E-01   0.0
       5      G      0.0            0.0            0.0            1.637925E-03  -6.083425E-01   0.0
       6      G      0.0            0.0            0.0            2.144940E-03  -5.625579E-01   0.0
       7      G      0.0            0.0            0.0            1.831866E-03  -4.615641E-01   0.0
       8      G      0.0            0.0            0.0            8.544188E-04  -3.360363E-01   0.0
       9      G      0.0            0.0            0.0           -4.132396E-04  -2.109802E-01   0.0
      10      G      0.0            0.0            0.0           -1.425787E-03  -9.825688E-02   0.0
      11      G      0.0            0.0            0.0           -1.861258E-03   4.669199E-03   0.0
      12      G      0.0            0.0            0.0            2.407061E-01   4.016065E-03   0.0
      13      G      0.0            0.0            2.356649E-01   2.176460E-01  -2.083704E-01   0.0
      14      G      0.0            0.0            4.273136E-01   1.558882E-01  -3.793500E-01   0.0
      15      G      0.0            0.0            5.435858E-01   7.227418E-02  -4.805576E-01   0.0
      16      G      0.0            0.0            5.732042E-01  -1.161800E-02  -5.023930E-01   0.0
      17      G      0.0            0.0            5.260984E-01  -7.671157E-02  -4.551033E-01   0.0
      18      G      0.0            0.0            4.275815E-01  -1.125037E-01  -3.631445E-01   0.0
      19      G      0.0            0.0            3.079631E-01  -1.196851E-01  -2.552617E-01   0.0
      20      G      0.0            0.0            1.916906E-01  -1.084777E-01  -1.540925E-01   0.0
      21      G      0.0            0.0            9.004164E-02  -9.352356E-02  -6.924665E-02   0.0
      22      G      0.0            0.0            0.0           -8.728099E-02   3.740484E-03   0.0
      23      G      0.0            0.0            0.0            4.129420E-01   1.594255E-03   0.0
      24      G      0.0            0.0            4.018800E-01   3.711607E-01  -1.121190E-01   0.0
      25      G      0.0            0.0            7.246771E-01   2.595806E-01  -1.975692E-01   0.0
      26      G      0.0            0.0            9.128082E-01   1.098559E-01  -2.362347E-01   0.0
      27      G      0.0            0.0            9.480194E-01  -3.757392E-02  -2.244534E-01   0.0
      28      G      0.0            0.0            8.512367E-01  -1.474027E-01  -1.738288E-01   0.0
      29      G      0.0            0.0            6.712680E-01  -2.009295E-01  -1.061428E-01   0.0
      30      G      0.0            0.0            4.650142E-01  -2.009573E-01  -4.481520E-02   0.0
      31      G      0.0            0.0            2.768810E-01  -1.684836E-01  -6.181870E-03   0.0
      32      G      0.0            0.0            1.251235E-01  -1.326589E-01   6.078871E-03   0.0
      33      G      0.0            0.0            0.0           -1.181246E-01   1.371021E-03   0.0
      34      G      0.0            0.0            0.0            4.689076E-01  -1.397782E-03   0.0
      35      G      0.0            0.0            4.538650E-01   4.164450E-01   1.010814E-02   0.0
      36      G      0.0            0.0            8.087885E-01   2.768967E-01   3.239833E-02   0.0
      37      G      0.0            0.0            9.969181E-01   9.260224E-02   7.103771E-02   0.0
      38      G      0.0            0.0            1.000000E+00  -8.280083E-02   1.223546E-01   0.0
      39      G      0.0            0.0            8.512324E-01  -2.033237E-01   1.738382E-01   0.0
      40      G      0.0            0.0            6.192792E-01  -2.461843E-01   2.082595E-01   0.0
      41      G      0.0            0.0            3.808975E-01  -2.182660E-01   2.100268E-01   0.0
      42      G      0.0            0.0            1.927649E-01  -1.512395E-01   1.713627E-01   0.0
      43      G      0.0            0.0            7.313786E-02  -8.746059E-02   9.593305E-02   0.0
      44      G      0.0            0.0            0.0           -6.224748E-02  -1.568791E-03   0.0
      45      G      0.0            0.0            0.0            4.033224E-01  -3.836978E-03   0.0
      46      G      0.0            0.0            3.865780E-01   3.492150E-01   1.162547E-01   0.0
      47      G      0.0            0.0            6.714876E-01   2.062137E-01   2.302049E-01   0.0
      48      G      0.0            0.0            7.877569E-01   2.216039E-02   3.313861E-01   0.0
      49      G      0.0            0.0            7.241048E-01  -1.430006E-01   4.101968E-01   0.0
      50      G      0.0            0.0            5.260893E-01  -2.391683E-01   4.551048E-01   0.0
      51      G      0.0            0.0            2.766623E-01  -2.439832E-01   4.553460E-01   0.0
      52      G      0.0            0.0            6.377798E-02  -1.699778E-01   4.044348E-01   0.0
      53      G      0.0            0.0           -5.249493E-02  -5.840428E-02   3.032410E-01   0.0
      54      G      0.0            0.0           -6.087280E-02   3.776640E-02   1.613606E-01   0.0
      55      G      0.0            0.0            0.0            7.503222E-02  -3.923689E-03   0.0
      56      G      0.0            0.0            0.0            2.515194E-01  -4.797455E-03   0.0
      57      G      0.0            0.0            2.352183E-01   2.034765E-01   1.715761E-01   0.0
      58      G      0.0            0.0            3.805875E-01   7.771879E-02   3.296865E-01   0.0
      59      G      0.0            0.0            3.805856E-01  -7.772297E-02   4.547616E-01   0.0
      60      G      0.0            0.0            2.352143E-01  -2.034771E-01   5.349331E-01   0.0
      61      G      0.0            0.0            4.570274E-14  -2.515111E-01   5.625395E-01   0.0
      62      G      0.0            0.0           -2.352143E-01  -2.034771E-01   5.349331E-01   0.0
      63      G      0.0            0.0           -3.805856E-01  -7.772297E-02   4.547616E-01   0.0
      64      G      0.0            0.0           -3.805875E-01   7.771879E-02   3.296865E-01   0.0
      65      G      0.0            0.0           -2.352183E-01   2.034765E-01   1.715761E-01   0.0
      66      G      0.0            0.0            0.0            2.515194E-01  -4.797455E-03   0.0
      67      G      0.0            0.0            0.0            7.503222E-02  -3.923689E-03   0.0
      68      G      0.0            0.0            6.087280E-02   3.776640E-02   1.613606E-01   0.0
      69      G      0.0            0.0            5.249493E-02  -5.840428E-02   3.032410E-01   0.0
      70      G      0.0            0.0           -6.377798E-02  -1.699778E-01   4.044348E-01   0.0
      71      G      0.0            0.0           -2.766623E-01  -2.439832E-01   4.553460E-01   0.0
      72      G      0.0            0.0           -5.260893E-01  -2.391683E-01   4.551048E-01   0.0
      73      G      0.0            0.0           -7.241048E-01  -1.430006E-01   4.101968E-01   0.0
      74      G      0.0            0.0           -7.877569E-01   2.216039E-02   3.313861E-01   0.0
      75      G      0.0            0.0           -6.714876E-01   2.062137E-01   2.302049E-01   0.0
      76      G      0.0            0.0           -3.865780E-01   3.492150E-01   1.162547E-01   0.0
      77      G      0.0            0.0            0.0            4.033224E-01  -3.836978E-03   0.0
      78      G      0.0            0.0            0.0           -6.224748E-02  -1.568791E-03   0.0
      79      G      0.0            0.0           -7.313786E-02  -8.746059E-02   9.593305E-02   0.0
      80      G      0.0            0.0           -1.927649E-01  -1.512395E-01   1.713627E-01   0.0
      81      G      0.0            0.0           -3.808975E-01  -2.182660E-01   2.100268E-01   0.0
      82      G      0.0            0.0           -6.192792E-01  -2.461843E-01   2.082595E-01   0.0
      83      G      0.0            0.0           -8.512324E-01  -2.033237E-01   1.738382E-01   0.0
      84      G      0.0            0.0           -1.000000E+00  -8.280083E-02   1.223546E-01   0.0
```

Listing 8-32 Output for Flutter Analysis of Square Panel Using Piston Theory (Continued)

```
    85      G      0.0           0.0           -9.969181E-01   9.260224E-02   7.103771E-02   0.0
    86      G      0.0           0.0           -8.087885E-01   2.768967E-01   3.239833E-02   0.0
    87      G      0.0           0.0           -4.538650E-01   4.164450E-01   1.010814E-02   0.0
    88      G      0.0           0.0            0.0            4.689076E-01  -1.397782E-03   0.0
    89      G      0.0           0.0            0.0           -1.181246E-01   1.371021E-03   0.0
    90      G      0.0           0.0           -1.251235E-01  -1.326589E-01   6.078871E-03   0.0
    91      G      0.0           0.0           -2.768810E-01  -1.684836E-01  -6.181870E-03   0.0
    92      G      0.0           0.0           -4.650142E-01  -2.009573E-01  -4.481520E-02   0.0
    93      G      0.0           0.0           -6.712680E-01  -2.009295E-01  -1.061428E-01   0.0
    94      G      0.0           0.0           -8.512367E-01  -1.474027E-01  -1.738288E-01   0.0
    95      G      0.0           0.0           -9.480194E-01  -3.757392E-02  -2.244534E-01   0.0
    96      G      0.0           0.0           -9.128082E-01   1.098559E-01  -2.362347E-01   0.0
    97      G      0.0           0.0           -7.246771E-01   2.595806E-01  -1.975692E-01   0.0
    98      G      0.0           0.0           -4.018800E-01   3.711607E-01  -1.121190E-01   0.0
    99      G      0.0           0.0            0.0            4.129420E-01   1.594255E-03   0.0
   100      G      0.0           0.0            0.0           -8.728099E-02   3.740484E-03   0.0
   101      G      0.0           0.0           -9.004164E-02  -9.352356E-02  -6.924665E-02   0.0
   102      G      0.0           0.0           -1.916906E-01  -1.084777E-01  -1.540925E-01   0.0
   103      G      0.0           0.0           -3.079631E-01  -1.196851E-01  -2.552617E-01   0.0
   104      G      0.0           0.0           -4.275815E-01  -1.125037E-01  -3.631445E-01   0.0
   105      G      0.0           0.0           -5.260984E-01  -7.671157E-02  -4.551033E-01   0.0
   106      G      0.0           0.0           -5.732042E-01  -1.161800E-02  -5.023930E-01   0.0
   107      G      0.0           0.0           -5.435858E-01   7.227418E-02  -4.805576E-01   0.0
   108      G      0.0           0.0           -4.273136E-01   1.558882E-01  -3.793500E-01   0.0
   109      G      0.0           0.0           -2.356649E-01   2.176460E-01  -2.083704E-01   0.0
   110      G      0.0           0.0            0.0            2.407061E-01   4.016065E-03   0.0
   111      G      0.0           0.0            0.0           -1.861258E-03   4.669199E-03   0.0
   112      G      0.0           0.0            0.0           -1.425787E-03  -9.825688E-02   0.0
   113      G      0.0           0.0            0.0           -4.132396E-04  -2.109802E-01   0.0
   114      G      0.0           0.0            0.0            8.544188E-04  -3.360363E-01   0.0
   115      G      0.0           0.0            0.0            1.831866E-03  -4.615641E-01   0.0
   116      G      0.0           0.0            0.0            2.144940E-03  -5.625579E-01   0.0
   117      G      0.0           0.0            0.0            1.637925E-03  -6.083425E-01   0.0
   118      G      0.0           0.0            0.0            4.719342E-04  -5.735155E-01   0.0
   119      G      0.0           0.0            0.0           -9.125334E-04  -4.484198E-01   0.0
   120      G      0.0           0.0            0.0           -2.042162E-03  -2.448997E-01   0.0
   121      G      0.0           0.0            0.0           -2.427032E-03   4.922156E-03   0.0
  1001      G      0.0           0.0            3.090505E-02   0.0           -1.178324E-01   0.0
  1002      G      0.0           0.0            8.678451E-02   0.0           -3.314892E-01   0.0
  1003      G      0.0           0.0            1.266528E-01   0.0           -4.854497E-01   0.0
  1004      G      0.0           0.0            1.449058E-01   0.0           -5.583950E-01   0.0
  1005      G      0.0           0.0            1.415278E-01   0.0           -5.496513E-01   0.0
  1006      G      0.0           0.0            1.214685E-01   0.0           -4.768399E-01   0.0
  1007      G      0.0           0.0            9.238999E-02   0.0           -3.677723E-01   0.0
  1008      G      0.0           0.0            6.173965E-02   0.0           -2.498269E-01   0.0
  1009      G      0.0           0.0            3.426860E-02   0.0           -1.408661E-01   0.0
  1010      G      0.0           0.0            1.084573E-02   0.0           -4.502082E-02   0.0
  2001      G      0.0           0.0            1.426601E-01   0.0           -8.310755E-02   0.0
  2002      G      0.0           0.0            4.003652E-01   0.0           -2.317893E-01   0.0
  2003      G      0.0           0.0            5.834715E-01   0.0           -3.332930E-01   0.0
  2004      G      0.0           0.0            6.659800E-01   0.0           -3.720188E-01   0.0
  2005      G      0.0           0.0            6.481806E-01   0.0           -3.499767E-01   0.0
  2006      G      0.0           0.0            5.535938E-01   0.0           -2.844124E-01   0.0
  2007      G      0.0           0.0            4.183482E-01   0.0           -2.003687E-01   0.0
  2008      G      0.0           0.0            2.773813E-01   0.0           -1.211207E-01   0.0
  2009      G      0.0           0.0            1.527319E-01   0.0           -6.013613E-02   0.0
  2010      G      0.0           0.0            4.807205E-02   0.0           -1.754093E-02   0.0
  3001      G      0.0           0.0            2.133086E-01   0.0           -2.599249E-02   0.0
  3002      G      0.0           0.0            5.960586E-01   0.0           -6.804819E-02   0.0
  3003      G      0.0           0.0            8.607312E-01   0.0           -8.411065E-02   0.0
  3004      G      0.0           0.0            9.677065E-01   0.0           -6.804526E-02   0.0
  3005      G      0.0           0.0            9.206281E-01   0.0           -2.598815E-02   0.0
  3006      G      0.0           0.0            7.608748E-01   0.0            2.599661E-02   0.0
  3007      G      0.0           0.0            5.494665E-01   0.0            6.805279E-02   0.0
  3008      G      0.0           0.0            3.437566E-01   0.0            8.411642E-02   0.0
  3009      G      0.0           0.0            1.778140E-01   0.0            6.805089E-02   0.0
  3010      G      0.0           0.0            5.355187E-02   0.0            2.599282E-02   0.0
  4001      G      0.0           0.0            2.251595E-01   0.0            3.364347E-02   0.0
  4002      G      0.0           0.0            6.234537E-01   0.0            1.022939E-01   0.0
  4003      G      0.0           0.0            8.826140E-01   0.0            1.732311E-01   0.0
  4004      G      0.0           0.0            9.591787E-01   0.0            2.425282E-01   0.0
  4005      G      0.0           0.0            8.641079E-01   0.0            3.005191E-01   0.0
  4006      G      0.0           0.0            6.548499E-01   0.0            3.338800E-01   0.0
  4007      G      0.0           0.0            4.113334E-01   0.0            3.298682E-01   0.0
  4008      G      0.0           0.0            2.054378E-01   0.0            2.811897E-01   0.0
  4009      G      0.0           0.0            7.560256E-02   0.0            1.896352E-01   0.0
  4010      G      0.0           0.0            1.589719E-02   0.0            6.700533E-02   0.0
```

Listing 8-32 Output for Flutter Analysis of Square Panel Using Piston Theory (Continued)

```
   5001     G      0.0          0.0           1.807391E-01   0.0          7.567985E-02   0.0
   5002     G      0.0          0.0           4.905497E-01   0.0          2.211299E-01   0.0
   5003     G      0.0          0.0           6.635824E-01   0.0          3.490358E-01   0.0
   5004     G      0.0          0.0           6.621167E-01   0.0          4.480309E-01   0.0
   5005     G      0.0          0.0           5.072617E-01   0.0          5.074899E-01   0.0
   5006     G      0.0          0.0           2.689662E-01   0.0          5.189829E-01   0.0
   5007     G      0.0          0.0           3.825030E-02   0.0          4.781200E-01   0.0
   5008     G      0.0          0.0          -1.075615E-01   0.0          3.862281E-01   0.0
   5009     G      0.0          0.0          -1.333238E-01   0.0          2.512190E-01   0.0
   5010     G      0.0          0.0          -5.756161E-02   0.0          8.717276E-02   0.0
   6001     G      0.0          0.0           1.011480E-01   0.0          8.717276E-02   0.0
   6002     G      0.0          0.0           2.589333E-01   0.0          2.512190E-01   0.0
   6003     G      0.0          0.0           3.006755E-01   0.0          3.862281E-01   0.0
   6004     G      0.0          0.0           2.008096E-01   0.0          4.781201E-01   0.0
   6005     G      0.0          0.0          -9.474851E-03   0.0          5.189829E-01   0.0
   6006     G      0.0          0.0          -2.535168E-01   0.0          5.074899E-01   0.0
   6007     G      0.0          0.0          -4.381014E-01   0.0          4.480309E-01   0.0
   6008     G      0.0          0.0          -4.890645E-01   0.0          3.490357E-01   0.0
   6009     G      0.0          0.0          -3.799848E-01   0.0          2.211299E-01   0.0
   6010     G      0.0          0.0          -1.428992E-01   0.0          7.567985E-02   0.0
   7001     G      0.0          0.0           1.760547E-02   0.0          6.700533E-02   0.0
   7002     G      0.0          0.0           1.921505E-02   0.0          1.896352E-01   0.0
   7003     G      0.0          0.0          -6.484304E-02   0.0          2.811897E-01   0.0
   7004     G      0.0          0.0          -2.463995E-01   0.0          3.298682E-01   0.0
   7005     G      0.0          0.0          -4.879100E-01   0.0          3.338800E-01   0.0
   7006     G      0.0          0.0          -7.138484E-01   0.0          3.005191E-01   0.0
   7007     G      0.0          0.0          -8.379146E-01   0.0          2.425282E-01   0.0
   7008     G      0.0          0.0          -7.959984E-01   0.0          1.732311E-01   0.0
   7009     G      0.0          0.0          -5.723068E-01   0.0          1.022939E-01   0.0
   7010     G      0.0          0.0          -2.083378E-01   0.0          3.364347E-02   0.0
   8001     G      0.0          0.0          -4.055545E-02   0.0          2.599282E-02   0.0
   8002     G      0.0          0.0          -1.437885E-01   0.0          6.805089E-02   0.0
   8003     G      0.0          0.0          -3.016984E-01   0.0          8.411642E-02   0.0
   8004     G      0.0          0.0          -5.154403E-01   0.0          6.805277E-02   0.0
   8005     G      0.0          0.0          -7.478766E-01   0.0          2.599659E-02   0.0
   8006     G      0.0          0.0          -9.336222E-01   0.0         -2.598817E-02   0.0
   8007     G      0.0          0.0          -1.001729E+00   0.0         -6.804528E-02   0.0
   8008     G      0.0          0.0          -9.027865E-01   0.0         -8.411065E-02   0.0
   8009     G      0.0          0.0          -6.300827E-01   0.0         -6.804819E-02   0.0
   8010     G      0.0          0.0          -2.263049E-01   0.0         -2.599249E-02   0.0
   9001     G      0.0          0.0          -5.684251E-02   0.0         -1.754093E-02   0.0
   9002     G      0.0          0.0          -1.828000E-01   0.0         -6.013613E-02   0.0
   9003     G      0.0          0.0          -3.379417E-01   0.0         -1.211208E-01   0.0
   9004     G      0.0          0.0          -5.185327E-01   0.0         -2.003688E-01   0.0
   9005     G      0.0          0.0          -6.958001E-01   0.0         -2.844124E-01   0.0
   9006     G      0.0          0.0          -8.231691E-01   0.0         -3.499768E-01   0.0
   9007     G      0.0          0.0          -8.519893E-01   0.0         -3.720188E-01   0.0
   9008     G      0.0          0.0          -7.501180E-01   0.0         -3.332930E-01   0.0
   9009     G      0.0          0.0          -5.162599E-01   0.0         -2.317893E-01   0.0
   9010     G      0.0          0.0          -1.842139E-01   0.0         -8.310755E-02   0.0
  10001     G      0.0          0.0          -3.335614E-02   0.0         -4.502082E-02   0.0
  10002     G      0.0          0.0          -1.047017E-01   0.0         -1.408661E-01   0.0
  10003     G      0.0          0.0          -1.866531E-01   0.0         -2.498269E-01   0.0
  10004     G      0.0          0.0          -2.762762E-01   0.0         -3.677724E-01   0.0
  10005     G      0.0          0.0          -3.598885E-01   0.0         -4.768400E-01   0.0
  10006     G      0.0          0.0          -4.163534E-01   0.0         -5.496513E-01   0.0
  10007     G      0.0          0.0          -4.241033E-01   0.0         -5.583950E-01   0.0
  10008     G      0.0          0.0          -3.693776E-01   0.0         -4.854497E-01   0.0
  10009     G      0.0          0.0          -2.525291E-01   0.0         -3.314892E-01   0.0
  10010     G      0.0          0.0          -8.982126E-02   0.0         -1.178324E-01   0.0
```

Listing 8-32 Output for Flutter Analysis of Square Panel Using Piston Theory (Continued)

```
0     EIGENVALUE =  1.585938E+06
         CYCLES =  2.004302E+02        R E A L   E I G E N V E C T O R   N O .        3

      POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
             1      G      0.0            0.0            0.0            4.669199E-03   1.861258E-03   0.0
             2      G      0.0            0.0            0.0            3.740484E-03   8.728099E-02   0.0
             3      G      0.0            0.0            0.0            1.371021E-03   1.181246E-01   0.0
             4      G      0.0            0.0            0.0           -1.568791E-03   6.224748E-02   0.0
             5      G      0.0            0.0            0.0           -3.923689E-03  -7.503222E-02   0.0
             6      G      0.0            0.0            0.0           -4.797455E-03  -2.515194E-01   0.0
             7      G      0.0            0.0            0.0           -3.836978E-03  -4.033224E-01   0.0
             8      G      0.0            0.0            0.0           -1.397782E-03  -4.689076E-01   0.0
             9      G      0.0            0.0            0.0            1.594255E-03  -4.129420E-01   0.0
            10      G      0.0            0.0            0.0            4.016065E-03  -2.407061E-01   0.0
            11      G      0.0            0.0            0.0            4.922156E-03   2.427032E-03   0.0
            12      G      0.0            0.0            0.0           -9.825688E-02   1.425787E-03   0.0
            13      G      0.0            0.0           -9.004164E-02  -6.924665E-02   9.352356E-02   0.0
            14      G      0.0            0.0           -1.251235E-01   6.078871E-03   1.326589E-01   0.0
            15      G      0.0            0.0           -7.313786E-02   9.593305E-02   8.746059E-02   0.0
            16      G      0.0            0.0            6.087280E-02   1.613606E-01  -3.776640E-02   0.0
            17      G      0.0            0.0            2.352183E-01   1.715761E-01  -2.034765E-01   0.0
            18      G      0.0            0.0            3.865780E-01   1.162547E-01  -3.492150E-01   0.0
            19      G      0.0            0.0            4.538650E-01   1.010814E-02  -4.164450E-01   0.0
            20      G      0.0            0.0            4.018800E-01  -1.121190E-01  -3.711607E-01   0.0
            21      G      0.0            0.0            2.356649E-01  -2.083704E-01  -2.176460E-01   0.0
            22      G      0.0            0.0            0.0           -2.448997E-01   2.042162E-03   0.0
            23      G      0.0            0.0            0.0           -2.109802E-01   4.132396E-04   0.0
            24      G      0.0            0.0           -1.916906E-01  -1.540925E-01   1.084777E-01   0.0
            25      G      0.0            0.0           -2.768810E-01  -6.181870E-03   1.684836E-01   0.0
            26      G      0.0            0.0           -1.927649E-01   1.713627E-01   1.512395E-01   0.0
            27      G      0.0            0.0            5.249493E-02   3.032410E-01   5.840428E-02   0.0
            28      G      0.0            0.0            3.805875E-01   3.296865E-01  -7.771879E-02   0.0
            29      G      0.0            0.0            6.714876E-01   2.302049E-01  -2.062137E-01   0.0
            30      G      0.0            0.0            8.087885E-01   3.239833E-02  -2.768967E-01   0.0
            31      G      0.0            0.0            7.246771E-01  -1.975692E-01  -2.595806E-01   0.0
            32      G      0.0            0.0            4.273136E-01  -3.793500E-01  -1.558882E-01   0.0
            33      G      0.0            0.0            0.0           -4.484198E-01   9.125334E-04   0.0
            34      G      0.0            0.0            0.0           -3.360363E-01  -8.544188E-04   0.0
            35      G      0.0            0.0           -3.079631E-01  -2.552617E-01   1.196851E-01   0.0
            36      G      0.0            0.0           -4.650142E-01  -4.481520E-02   2.009573E-01   0.0
            37      G      0.0            0.0           -3.808975E-01   2.100268E-01   2.182660E-01   0.0
            38      G      0.0            0.0           -6.377798E-02   4.044348E-01   1.699778E-01   0.0
            39      G      0.0            0.0            3.805856E-01   4.547616E-01   7.772297E-02   0.0
            40      G      0.0            0.0            7.877569E-01   3.313861E-01  -2.216039E-02   0.0
            41      G      0.0            0.0            9.969181E-01   7.103771E-02  -9.260224E-02   0.0
            42      G      0.0            0.0            9.128082E-01  -2.362347E-01  -1.098559E-01   0.0
            43      G      0.0            0.0            5.435858E-01  -4.805576E-01  -7.227418E-02   0.0
            44      G      0.0            0.0            0.0           -5.735155E-01  -4.719342E-04   0.0
            45      G      0.0            0.0            0.0           -4.615641E-01  -1.831866E-03   0.0
            46      G      0.0            0.0           -4.275815E-01  -3.631445E-01   1.125037E-01   0.0
            47      G      0.0            0.0           -6.712680E-01  -1.061428E-01   2.009295E-01   0.0
            48      G      0.0            0.0           -6.192792E-01   2.082595E-01   2.461843E-01   0.0
            49      G      0.0            0.0           -2.766623E-01   4.553460E-01   2.439832E-01   0.0
            50      G      0.0            0.0            2.352143E-01   5.349331E-01   2.034771E-01   0.0
            51      G      0.0            0.0            7.241048E-01   4.101968E-01   1.430006E-01   0.0
            52      G      0.0            0.0            1.000000E+00   1.223546E-01   8.280083E-02   0.0
            53      G      0.0            0.0            9.480194E-01  -2.244534E-01   3.757392E-02   0.0
            54      G      0.0            0.0            5.732042E-01  -5.023930E-01   1.161800E-02   0.0
            55      G      0.0            0.0            0.0           -6.083425E-01  -1.637925E-03   0.0
            56      G      0.0            0.0            0.0           -5.625579E-01  -2.144940E-03   0.0
            57      G      0.0            0.0           -5.260984E-01  -4.551033E-01   7.671157E-02   0.0
            58      G      0.0            0.0           -8.512367E-01  -1.738288E-01   1.474027E-01   0.0
            59      G      0.0            0.0           -8.512324E-01   1.738382E-01   2.033237E-01   0.0
            60      G      0.0            0.0           -5.260893E-01   4.551048E-01   2.391683E-01   0.0
            61      G      0.0            0.0            1.993383E-13   5.625395E-01   2.515111E-01   0.0
            62      G      0.0            0.0            5.260893E-01   4.551048E-01   2.391683E-01   0.0
            63      G      0.0            0.0            8.512324E-01   1.738382E-01   2.033237E-01   0.0
            64      G      0.0            0.0            8.512367E-01  -1.738288E-01   1.474027E-01   0.0
            65      G      0.0            0.0            5.260984E-01  -4.551033E-01   7.671157E-02   0.0
            66      G      0.0            0.0            0.0           -5.625579E-01  -2.144940E-03   0.0
            67      G      0.0            0.0            0.0           -6.083425E-01  -1.637925E-03   0.0
            68      G      0.0            0.0           -5.732042E-01  -5.023930E-01   1.161800E-02   0.0
            69      G      0.0            0.0           -9.480194E-01  -2.244534E-01   3.757392E-02   0.0
            70      G      0.0            0.0           -1.000000E+00   1.223546E-01   8.280083E-02   0.0
            71      G      0.0            0.0           -7.241048E-01   4.101968E-01   1.430006E-01   0.0
            72      G      0.0            0.0           -2.352143E-01   5.349331E-01   2.034771E-01   0.0
            73      G      0.0            0.0            2.766623E-01   4.553460E-01   2.439832E-01   0.0
            74      G      0.0            0.0            6.192792E-01   2.082595E-01   2.461843E-01   0.0
            75      G      0.0            0.0            6.712680E-01  -1.061428E-01   2.009295E-01   0.0
```

Main Index

Listing 8-32 Output for Flutter Analysis of Square Panel Using Piston Theory (Continued)

```
      76      G      0.0            0.0            4.275815E-01  -3.631445E-01   1.125037E-01   0.0
      77      G      0.0            0.0            0.0           -4.615641E-01  -1.831866E-03   0.0
      78      G      0.0            0.0            0.0           -5.735155E-01  -4.719342E-04   0.0
      79      G      0.0            0.0           -5.435858E-01  -4.805576E-01  -7.227418E-02   0.0
      80      G      0.0            0.0           -9.128082E-01  -2.362347E-01  -1.098559E-01   0.0
      81      G      0.0            0.0           -9.969181E-01   7.103771E-02  -9.260224E-02   0.0
      82      G      0.0            0.0           -7.877569E-01   3.313861E-01  -2.216039E-02   0.0
      83      G      0.0            0.0           -3.805856E-01   4.547616E-01   7.772297E-02   0.0
      84      G      0.0            0.0            6.377798E-02   4.044348E-01   1.699778E-01   0.0
      85      G      0.0            0.0            3.808975E-01   2.100268E-01   2.182660E-01   0.0
      86      G      0.0            0.0            4.650142E-01  -4.481520E-02   2.009573E-01   0.0
      87      G      0.0            0.0            3.079631E-01  -2.552617E-01   1.196851E-01   0.0
      88      G      0.0            0.0            0.0           -3.360363E-01  -8.544188E-04   0.0
      89      G      0.0            0.0            0.0           -4.484198E-01   9.125334E-04   0.0
      90      G      0.0            0.0           -4.273136E-01  -3.793500E-01  -1.558882E-01   0.0
      91      G      0.0            0.0           -7.246771E-01  -1.975692E-01  -2.595806E-01   0.0
      92      G      0.0            0.0           -8.087885E-01   3.239833E-02  -2.768967E-01   0.0
      93      G      0.0            0.0           -6.714876E-01   2.302049E-01  -2.062137E-01   0.0
      94      G      0.0            0.0           -3.805875E-01   3.296865E-01  -7.771879E-02   0.0
      95      G      0.0            0.0           -5.249493E-02   3.032410E-01   5.840428E-02   0.0
      96      G      0.0            0.0            1.927649E-01   1.713627E-01   1.512395E-01   0.0
      97      G      0.0            0.0            2.768810E-01  -6.181870E-03   1.684836E-01   0.0
      98      G      0.0            0.0            1.916906E-01  -1.540925E-01   1.084777E-01   0.0
      99      G      0.0            0.0            0.0           -2.109802E-01   4.132396E-04   0.0
     100      G      0.0            0.0            0.0           -2.448997E-01   2.042162E-03   0.0
     101      G      0.0            0.0           -2.356649E-01  -2.083704E-01  -2.176460E-01   0.0
     102      G      0.0            0.0           -4.018800E-01  -1.121190E-01  -3.711607E-01   0.0
     103      G      0.0            0.0           -4.538650E-01   1.010814E-02  -4.164450E-01   0.0
     104      G      0.0            0.0           -3.865780E-01   1.162547E-01  -3.492150E-01   0.0
     105      G      0.0            0.0           -2.352183E-01   1.715761E-01  -2.034765E-01   0.0
     106      G      0.0            0.0           -6.087280E-02   1.613606E-01  -3.776640E-02   0.0
     107      G      0.0            0.0            7.313786E-02   9.593305E-02   8.746059E-02   0.0
     108      G      0.0            0.0            1.251235E-01   6.078871E-03   1.326589E-01   0.0
     109      G      0.0            0.0            9.004164E-02  -6.924665E-02   9.352356E-02   0.0
     110      G      0.0            0.0            0.0           -9.825688E-02   1.425787E-03   0.0
     111      G      0.0            0.0            0.0            4.922156E-03   2.427032E-03   0.0
     112      G      0.0            0.0            0.0            4.016065E-03  -2.407061E-01   0.0
     113      G      0.0            0.0            0.0            1.594255E-03  -4.129420E-01   0.0
     114      G      0.0            0.0            0.0           -1.397782E-03  -4.689076E-01   0.0
     115      G      0.0            0.0            0.0           -3.836978E-03  -4.033224E-01   0.0
     116      G      0.0            0.0            0.0           -4.797455E-03  -2.515194E-01   0.0
     117      G      0.0            0.0            0.0           -3.923689E-03  -7.503222E-02   0.0
     118      G      0.0            0.0            0.0           -1.568791E-03   6.224748E-02   0.0
     119      G      0.0            0.0            0.0            1.371021E-03   1.181246E-01   0.0
     120      G      0.0            0.0            0.0            3.740484E-03   8.728099E-02   0.0
     121      G      0.0            0.0            0.0            4.669199E-03   1.861258E-03   0.0
    1001      G      0.0            0.0           -1.309935E-02   0.0            4.502082E-02   0.0
    1002      G      0.0            0.0           -3.166817E-02   0.0            1.075826E-01   0.0
    1003      G      0.0            0.0           -3.047854E-02   0.0            9.913067E-02   0.0
    1004      G      0.0            0.0           -5.681969E-03   0.0            6.132499E-03   0.0
    1005      G      0.0            0.0            3.636016E-02   0.0           -1.480456E-01   0.0
    1006      G      0.0            0.0            8.122538E-02   0.0           -3.108982E-01   0.0
    1007      G      0.0            0.0            1.117768E-01   0.0           -4.202215E-01   0.0
    1008      G      0.0            0.0            1.147087E-01   0.0           -4.278724E-01   0.0
    1009      G      0.0            0.0            8.579095E-02   0.0           -3.187724E-01   0.0
    1010      G      0.0            0.0            3.176610E-02   0.0           -1.178324E-01   0.0
    2001      G      0.0            0.0           -6.314153E-02   0.0            5.082448E-02   0.0
    2002      G      0.0            0.0           -1.532884E-01   0.0            1.267032E-01   0.0
    2003      G      0.0            0.0           -1.498631E-01   0.0            1.356923E-01   0.0
    2004      G      0.0            0.0           -3.452995E-02   0.0            6.400242E-02   0.0
    2005      G      0.0            0.0            1.628782E-01   0.0           -6.849566E-02   0.0
    2006      G      0.0            0.0            3.744347E-01   0.0           -2.151395E-01   0.0
    2007      G      0.0            0.0            5.193326E-01   0.0           -3.199167E-01   0.0
    2008      G      0.0            0.0            5.347499E-01   0.0           -3.388604E-01   0.0
    2009      G      0.0            0.0            4.005778E-01   0.0           -2.572230E-01   0.0
    2010      G      0.0            0.0            1.484178E-01   0.0           -9.582436E-02   0.0
    3001      G      0.0            0.0           -1.190025E-01   0.0            5.813625E-02   0.0
    3002      G      0.0            0.0           -2.947320E-01   0.0            1.522028E-01   0.0
    3003      G      0.0            0.0           -3.088797E-01   0.0            1.881329E-01   0.0
    3004      G      0.0            0.0           -1.285621E-01   0.0            1.522027E-01   0.0
    3005      G      0.0            0.0            1.972445E-01   0.0            5.813742E-02   0.0
    3006      G      0.0            0.0            5.545548E-01   0.0           -5.813370E-02   0.0
    3007      G      0.0            0.0            8.068895E-01   0.0           -1.521994E-01   0.0
    3008      G      0.0            0.0            8.474056E-01   0.0           -1.881303E-01   0.0
    3009      G      0.0            0.0            6.407301E-01   0.0           -1.522016E-01   0.0
    3010      G      0.0            0.0            2.383157E-01   0.0           -5.813611E-02   0.0
```

Listing 8-32 Output for Flutter Analysis of Square Panel Using Piston Theory (Continued)

```
      4001      G      0.0            0.0           -1.801340E-01   0.0            5.980922E-02   0.0
      4002      G      0.0            0.0           -4.563987E-01   0.0            1.629362E-01   0.0
      4003      G      0.0            0.0           -5.140654E-01   0.0            2.223178E-01   0.0
      4004      G      0.0            0.0           -3.062881E-01   0.0            2.256330E-01   0.0
      4005      G      0.0            0.0            1.055455E-01   0.0            1.791278E-01   0.0
      4006      G      0.0            0.0            5.735800E-01   0.0            1.045117E-01   0.0
      4007      G      0.0            0.0            9.190436E-01   0.0            3.028506E-02   0.0
      4008      G      0.0            0.0            1.000533E+00   0.0           -1.914653E-02   0.0
      4009      G      0.0            0.0            7.689465E-01   0.0           -3.241478E-02   0.0
      4010      G      0.0            0.0            2.879103E-01   0.0           -1.480919E-02   0.0
      5001      G      0.0            0.0           -2.389600E-01   0.0            4.925841E-02   0.0
      5002      G      0.0            0.0           -6.178321E-01   0.0            1.392427E-01   0.0
      5003      G      0.0            0.0           -7.380867E-01   0.0            2.059609E-01   0.0
      5004      G      0.0            0.0           -5.411148E-01   0.0            2.406901E-01   0.0
      5005      G      0.0            0.0           -9.296473E-02   0.0            2.423206E-01   0.0
      5006      G      0.0            0.0            4.400161E-01   0.0            2.166149E-01   0.0
      5007      G      0.0            0.0            8.542488E-01   0.0            1.733915E-01   0.0
      5008      G      0.0            0.0            9.866834E-01   0.0            1.227751E-01   0.0
      5009      G      0.0            0.0            7.775476E-01   0.0            7.194424E-02   0.0
      5010      G      0.0            0.0            2.940325E-01   0.0            2.355291E-02   0.0
      6001      G      0.0            0.0           -2.822561E-01   0.0            2.355291E-02   0.0
      6002      G      0.0            0.0           -7.415755E-01   0.0            7.194424E-02   0.0
      6003      G      0.0            0.0           -9.252958E-01   0.0            1.227752E-01   0.0
      6004      G      0.0            0.0           -7.675529E-01   0.0            1.733916E-01   0.0
      6005      G      0.0            0.0           -3.317084E-01   0.0            2.166149E-01   0.0
      6006      G      0.0            0.0            2.141253E-01   0.0            2.423206E-01   0.0
      6007      G      0.0            0.0            6.614601E-01   0.0            2.406901E-01   0.0
      6008      G      0.0            0.0            8.410672E-01   0.0            2.059609E-01   0.0
      6009      G      0.0            0.0            6.874534E-01   0.0            1.392427E-01   0.0
      6010      G      0.0            0.0            2.635892E-01   0.0            4.925841E-02   0.0
      7001      G      0.0            0.0           -2.953149E-01   0.0           -1.480919E-02   0.0
      7002      G      0.0            0.0           -7.851539E-01   0.0           -3.241478E-02   0.0
      7003      G      0.0            0.0           -1.010106E+00   0.0           -1.914652E-02   0.0
      7004      G      0.0            0.0           -9.039009E-01   0.0            3.028511E-02   0.0
      7005      G      0.0            0.0           -5.213240E-01   0.0            1.045117E-01   0.0
      7006      G      0.0            0.0           -1.598135E-02   0.0            1.791279E-01   0.0
      7007      G      0.0            0.0            4.191048E-01   0.0            2.256331E-01   0.0
      7008      G      0.0            0.0            6.252244E-01   0.0            2.223178E-01   0.0
      7009      G      0.0            0.0            5.378668E-01   0.0            1.629362E-01   0.0
      7010      G      0.0            0.0            2.100386E-01   0.0            5.980922E-02   0.0
      8001      G      0.0            0.0           -2.673837E-01   0.0           -5.813611E-02   0.0
      8002      G      0.0            0.0           -7.168308E-01   0.0           -1.522016E-01   0.0
      8003      G      0.0            0.0           -9.414708E-01   0.0           -1.881303E-01   0.0
      8004      G      0.0            0.0           -8.829891E-01   0.0           -1.521994E-01   0.0
      8005      G      0.0            0.0           -5.836215E-01   0.0           -5.813365E-02   0.0
      8006      G      0.0            0.0           -1.681756E-01   0.0            5.813748E-02   0.0
      8007      G      0.0            0.0            2.046636E-01   0.0            1.522028E-01   0.0
      8008      G      0.0            0.0            4.029462E-01   0.0            1.881329E-01   0.0
      8009      G      0.0            0.0            3.708335E-01   0.0            1.522028E-01   0.0
      8010      G      0.0            0.0            1.480706E-01   0.0            5.813625E-02   0.0
      9001      G      0.0            0.0           -1.963300E-01   0.0           -9.582436E-02   0.0
      9002      G      0.0            0.0           -5.291893E-01   0.0           -2.572230E-01   0.0
      9003      G      0.0            0.0           -7.041802E-01   0.0           -3.388604E-01   0.0
      9004      G      0.0            0.0           -6.792909E-01   0.0           -3.199166E-01   0.0
      9005      G      0.0            0.0           -4.820043E-01   0.0           -2.151394E-01   0.0
      9006      G      0.0            0.0           -1.971259E-01   0.0           -6.849559E-02   0.0
      9007      G      0.0            0.0            6.653132E-02   0.0            6.400249E-02   0.0
      9008      G      0.0            0.0            2.177092E-01   0.0            1.356923E-01   0.0
      9009      G      0.0            0.0            2.166400E-01   0.0            1.267032E-01   0.0
      9010      G      0.0            0.0            8.855377E-02   0.0            5.082448E-02   0.0
     10001      G      0.0            0.0           -9.068232E-02   0.0           -1.178324E-01   0.0
     10002      G      0.0            0.0           -2.451772E-01   0.0           -3.187724E-01   0.0
     10003      G      0.0            0.0           -3.286449E-01   0.0           -4.278725E-01   0.0
     10004      G      0.0            0.0           -3.218875E-01   0.0           -4.202214E-01   0.0
     10005      G      0.0            0.0           -2.366744E-01   0.0           -3.108982E-01   0.0
     10006      G      0.0            0.0           -1.103829E-01   0.0           -1.480455E-01   0.0
     10007      G      0.0            0.0            8.748291E-03   0.0            6.132595E-03   0.0
     10008      G      0.0            0.0            8.004388E-02   0.0            9.913068E-02   0.0
     10009      G      0.0            0.0            8.545946E-02   0.0            1.075826E-01   0.0
     10010      G      0.0            0.0            3.560976E-02   0.0            4.502082E-02   0.0
```

Listing 8-32 Output for Flutter Analysis of Square Panel Using Piston Theory (Continued)

```
                                        FLUTTER  SUMMARY
 POINT =    1     MACH NUMBER =  2.0000     DENSITY RATIO =  5.0000E-01     METHOD = PK

 KFREQ          1./KFREQ         VELOCITY          DAMPING          FREQUENCY             COMPLEX   EIGENVALUE
  0.2087      4.7904491E+00    1.8000000E+03   -1.5183085E-01    1.4352501E+02    -6.8460098E+01     9.0179431E+02
  0.2347      4.2612085E+00    1.9000000E+03   -2.2514819E-01    1.7031471E+02    -1.2046767E+02     1.0701189E+03
  0.2323      4.3047180E+00    1.9500000E+03   -3.4828857E-01    1.7302994E+02    -1.8932603E+02     1.0871792E+03
  0.2302      4.3440037E+00    2.0000000E+03   -4.2062744E-01    1.7586166E+02    -2.3239066E+02     1.1049714E+03
  0.2243      4.4580016E+00    2.2000000E+03   -5.9151113E-01    1.8850107E+02    -3.5028909E+02     1.1843872E+03
  0.2218      4.5085921E+00    2.4000000E+03   -6.8576783E-01    2.0333009E+02    -4.3805499E+02     1.2775607E+03
  0.2216      4.5123258E+00    2.4500000E+03   -7.0259273E-01    2.0739436E+02    -4.5777335E+02     1.3030973E+03
  0.2216      4.5127783E+00    2.5000000E+03   -7.1737355E-01    2.1160571E+02    -4.7689487E+02     1.3295580E+03
  0.2220      4.5044394E+00    2.6000000E+03   -7.4176371E-01    2.2047734E+02    -5.1378265E+02     1.3853000E+03

      POINT =    2     MACH NUMBER =  2.0000     DENSITY RATIO =  5.0000E-01     METHOD = PK

 KFREQ          1./KFREQ         VELOCITY          DAMPING          FREQUENCY             COMPLEX   EIGENVALUE
  0.2722      3.6741130E+00    1.8000000E+03   -1.1624902E-01    1.8713342E+02    -6.8342453E+01     1.1757941E+03
  0.2348      4.2597957E+00    1.9000000E+03   -4.4721335E-02    1.7037120E+02    -2.3936510E+01     1.0704739E+03
  0.2323      4.3041105E+00    1.9500000E+03    7.5636230E-02    1.7305435E+02     4.1120871E+01     1.0873326E+03
  0.2302      4.3435454E+00    2.0000000E+03    1.4548054E-01    1.7588022E+02     8.0384399E+01     1.1050880E+03
  0.2243      4.4577065E+00    2.2000000E+03    3.0912995E-01    1.8851357E+02     1.8307692E+02     1.1844657E+03
  0.2218      4.5083399E+00    2.4000000E+03    4.0016800E-01    2.0334145E+02     2.5563374E+02     1.2776321E+03
  0.2216      4.5120788E+00    2.4500000E+03    4.1675222E-01    2.0740573E+02     2.7154922E+02     1.3031687E+03
  0.2216      4.5125346E+00    2.5000000E+03    4.3149984E-01    2.1161714E+02     2.8686752E+02     1.3296298E+03
  0.2220      4.5041981E+00    2.6000000E+03    4.5640814E-01    2.2048915E+02     3.1614804E+02     1.3853743E+03

 POINT =    3     MACH NUMBER =  2.0000     DENSITY RATIO =  5.0000E-01     METHOD = PK

 KFREQ          1./KFREQ         VELOCITY          DAMPING          FREQUENCY             COMPLEX   EIGENVALUE
  0.3140      3.1845033E+00    1.8000000E+03   -1.0585071E-01    2.1590474E+02    -7.1796928E+01     1.3565696E+03
  0.3027      3.3038633E+00    1.9000000E+03   -1.0982659E-01    2.1966603E+02    -7.5791466E+01     1.3802024E+03
  0.2978      3.3583839E+00    1.9500000E+03   -1.1164407E-01    2.2178677E+02    -7.7789536E+01     1.3935275E+03
  0.2933      3.4092307E+00    2.0000000E+03   -1.1334021E-01    2.2408096E+02    -7.9788239E+01     1.4079423E+03
  0.2799      3.5722883E+00    2.2000000E+03   -1.1879526E-01    2.3523805E+02    -8.7792328E+01     1.4780443E+03
  0.2732      3.6603711E+00    2.4000000E+03   -1.2179092E-01    2.5044794E+02    -9.5825752E+01     1.5736108E+03
  0.2726      3.6681280E+00    2.4500000E+03   -1.2207674E-01    2.5512497E+02    -9.7844360E+01     1.6029976E+03
  0.2726      3.6687770E+00    2.5000000E+03   -1.2213536E-01    2.6028555E+02    -9.9871452E+01     1.6354225E+03
  0.2746      3.6413260E+00    2.6000000E+03   -1.2136049E-01    2.7273770E+02    -1.0398540E+02     1.7136615E+03

 POINT =    4     MACH NUMBER =  2.0000     DENSITY RATIO =  5.0000E-01     METHOD = PK

 KFREQ          1./KFREQ         VELOCITY          DAMPING          FREQUENCY             COMPLEX   EIGENVALUE
  0.4678      2.1377494E+00    1.8000000E+03   -7.0856951E-02    3.2162299E+02    -7.1594460E+01     2.0208169E+03
  0.4432      2.2563396E+00    1.9000000E+03   -7.4784920E-02    3.2164771E+02    -7.5569122E+01     2.0209723E+03
  0.4318      2.3157427E+00    1.9500000E+03   -7.6752007E-02    3.2164417E+02    -7.7555984E+01     2.0209500E+03
  0.4210      2.3752625E+00    2.0000000E+03   -7.8722581E-02    3.2162494E+02    -7.9542442E+01     2.0208291E+03
  0.3823      2.6157110E+00    2.2000000E+03   -8.6677067E-02    3.2126566E+02    -8.7481941E+01     2.0185718E+03
  0.3489      2.8661566E+00    2.4000000E+03   -9.4939411E-02    3.1984729E+02    -9.5397964E+01     2.0096599E+03
  0.3410      2.9324751E+00    2.4500000E+03   -9.7118646E-02    3.1912668E+02    -9.7367859E+01     2.0051321E+03
  0.3332      3.0016396E+00    2.5000000E+03   -9.9384069E-02    3.1813602E+02    -9.9329788E+01     1.9989076E+03
  0.3169      3.1559603E+00    2.6000000E+03   -1.0438508E-01    3.1468289E+02    -1.0319566E+02     1.9772111E+03

 POINT =    5     MACH NUMBER =  3.0000     DENSITY RATIO =  5.0000E-01     METHOD = PK

 KFREQ          1./KFREQ         VELOCITY          DAMPING          FREQUENCY             COMPLEX   EIGENVALUE
  0.1505      6.6425405E+00    1.8000000E+03   -1.2886114E-01    1.0350698E+02    -4.1902653E+01     6.5035358E+02
  0.1504      6.6493044E+00    1.9000000E+03   -1.2899652E-01    1.0914623E+02    -4.4232006E+01     6.8578601E+02
  0.1508      6.6328869E+00    1.9500000E+03   -1.2868065E-01    1.1229577E+02    -4.5396935E+01     7.0557513E+02
  0.1514      6.6033998E+00    2.0000000E+03   -1.2811172E-01    1.1568945E+02    -4.6562096E+01     7.2689832E+02
  0.1575      6.3485928E+00    2.2000000E+03   -1.2318996E-01    1.3236604E+02    -5.1227341E+01     8.3168042E+02
  0.1763      5.6734242E+00    2.4000000E+03   -1.1028760E-01    1.6158362E+02    -5.5985287E+01     1.0152599E+03
  0.1831      5.4600530E+00    2.4500000E+03   -2.5049758E-01    1.7139595E+02    -1.3488200E+02     1.0769126E+03
  0.1817      5.5026503E+00    2.5000000E+03   -3.2879058E-01    1.7353995E+02    -1.7925394E+02     1.0903837E+03
  0.1793      5.5774884E+00    2.6000000E+03   -4.2926401E-01    1.7805984E+02    -2.4012665E+02     1.1187831E+03

 POINT =    6     MACH NUMBER =  3.0000     DENSITY RATIO =  5.0000E-01     METHOD = PK

 KFREQ          1./KFREQ         VELOCITY          DAMPING          FREQUENCY             COMPLEX   EIGENVALUE
  0.2876      3.4776528E+00    1.8000000E+03   -6.7410626E-02    1.9770499E+02    -4.1869316E+01     1.2422172E+03
  0.2712      3.6873910E+00    1.9000000E+03   -7.1474388E-02    1.9681844E+02    -4.4194286E+01     1.2366467E+03
  0.2635      3.7951260E+00    1.9500000E+03   -7.3561460E-02    1.9626361E+02    -4.5356548E+01     1.2331606E+03
  0.2561      3.9053950E+00    2.0000000E+03   -7.5697303E-02    1.9561240E+02    -4.6518604E+01     1.2290690E+03
  0.2278      4.3902888E+00    2.2000000E+03   -8.5082710E-02    1.9140839E+02    -5.1162548E+01     1.2026544E+03
  0.1932      5.1759119E+00    2.4000000E+03   -1.0012950E-01    1.7711516E+02    -5.5714428E+01     1.1128474E+03
  0.1832      5.4591718E+00    2.4500000E+03    3.8724344E-02    1.7142361E+02     2.0854733E+01     1.0770864E+03
  0.1817      5.5020719E+00    2.5000000E+03    1.1535835E-01    1.7355818E+02     6.2899044E+01     1.0904983E+03
  0.1793      5.5770836E+00    2.6000000E+03    2.1292362E-01    1.7807277E+02     1.1911631E+02     1.1188643E+03
```

Listing 8-32 Output for Flutter Analysis of Square Panel Using Piston Theory (Continued)

```
POINT =    7     MACH NUMBER =  3.0000     DENSITY RATIO =  5.0000E-01     METHOD = PK

KFREQ           1./KFREQ          VELOCITY          DAMPING           FREQUENCY           COMPLEX   EIGENVALUE
 0.3000       3.3334911E+00    1.8000000E+03    -6.7840591E-02     2.0625502E+02     -4.3958622E+01     1.2959386E+03
 0.2861       3.4946914E+00    1.9000000E+03    -7.1122944E-02     2.0767114E+02     -4.6401901E+01     1.3048363E+03
 0.2799       3.5729437E+00    1.9500000E+03    -7.2716504E-02     2.0846820E+02     -4.7623653E+01     1.3098444E+03
 0.2740       3.6494915E+00    2.0000000E+03    -7.4275538E-02     2.0932880E+02     -4.8845512E+01     1.3152517E+03
 0.2540       3.9365015E+00    2.2000000E+03    -8.0122933E-02     2.1347331E+02     -5.3734142E+01     1.3412925E+03
 0.2388       4.1876168E+00    2.4000000E+03    -8.5243277E-02     2.1891507E+02     -5.8625381E+01     1.3754840E+03
 0.2356       4.2439756E+00    2.4500000E+03    -8.6393394E-02     2.2050812E+02     -5.9848740E+01     1.3854934E+03
 0.2327       4.2975521E+00    2.5000000E+03    -8.7487258E-02     2.2220316E+02     -6.1072392E+01     1.3961437E+03
 0.2275       4.3959293E+00    2.6000000E+03    -8.9497574E-02     2.2591963E+02     -6.3520679E+01     1.4194950E+03

POINT =    8     MACH NUMBER =  3.0000     DENSITY RATIO =  5.0000E-01     METHOD = PK

KFREQ           1./KFREQ          VELOCITY          DAMPING           FREQUENCY           COMPLEX   EIGENVALUE
 0.4675       2.1388676E+00    1.8000000E+03    -4.3416854E-02     3.2145486E+02     -4.3845825E+01     2.0197605E+03
 0.4430       2.2573581E+00    1.9000000E+03    -4.5821652E-02     3.2150262E+02     -4.6281258E+01     2.0200607E+03
 0.4317       2.3165796E+00    1.9500000E+03    -4.7023520E-02     3.2152795E+02     -4.7498924E+01     2.0202198E+03
 0.4209       2.3757868E+00    2.0000000E+03    -4.8225053E-02     3.2155399E+02     -4.8716545E+01     2.0203833E+03
 0.3828       2.6125252E+00    2.2000000E+03    -5.3028762E-02     3.2165741E+02     -5.3586445E+01     2.0210332E+03
 0.3510       2.8493795E+00    2.4000000E+03    -5.7833485E-02     3.2173053E+02     -5.8454983E+01     2.0214927E+03
 0.3438       2.9086857E+00    2.4500000E+03    -5.9036233E-02     3.2173672E+02     -5.9671806E+01     2.0215316E+03
 0.3369       2.9680619E+00    2.5000000E+03    -6.0240243E-02     3.2173508E+02     -6.0888466E+01     2.0215212E+03
 0.3239       3.0871236E+00    2.6000000E+03    -6.2653899E-02     3.2169971E+02     -6.3321129E+01     2.0212990E+03
```

Listing 8-33 Input Data for Flutter Analysis of Square Panel Using ZONA51 Aerodynamics

```
   N A S T R A N    E X E C U T I V E    C O N T R O L    D E C K    E C H O

 ID MSC, HA145HB
 TIME 45
 SOL 145
 CEND



3D PANEL FLUTTER                                                                                           PAGE     2
 PINNED EDGES
 ZONA51 AERO, EXAMPLE HA145HB
                                   C A S E    C O N T R O L    D E C K    E C H O

            CARD
            COUNT
             1      $
             2      TITLE = 3D PANEL FLUTTER
             3      SUBTI = PINNED EDGES
             4      LABEL = ZONA51 AERO, EXAMPLE HA145HB
             5        ECHO     = BOTH
             6        METHOD   = 20
             7        FMETHOD  = 30
             8        SPC      = 1
             9        SET   10 = 1 THRU 999999
            10        DISP     = 10
            11      BEGIN BULK
```

Listing 8-33 Input Data for Flutter Analysis of Square Panel Using ZONA51 Aerodynamics (Continued)

```
 3D PANEL FLUTTER                                                                                            PAGE     3
   PINNED EDGES
  ZONA51 AERO, EXAMPLE HA145HB
                                            I N P U T   B U L K   D A T A   D E C K   E C H O

                                   .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                                   $
                                   INCLUDE PANEL_STRUCT.DAT
                                   $
                                   $ CAERO FOR PANEL SURFACE
                                   $       EID     PID     CP      NSPAN   NCHORD  LSPAN   LCHORD  IGID    +CA
                                   CAERO1  1001    1       0       10      10                      1       +CA1
                                   $       X1      Y1      Z1      X12     X4      Y4      Z4      X14
                                   +CA1    0.0     0.0     0.0     10.0    0.0     10.0    0.0     10.0
                                   $ CAERO FOR SURFACE INBOARD OF PANEL
                                   CAERO1  2001    1       0       10      10                      1       +CA2
                                   +CA2    0.0     -10.0   0.0     10.0    0.0     0.0     0.0     10.0
                                   $ CAERO FOR SURFACE OUTBOARD OF SURFACE
                                   CAERO1  3001    1       0       10      10                      1       +CA3
                                   +CA3    0.0     10.0    0.0     10.0    0.0     20.0    0.0     10.0
                                   $
                                   PAERO1  1
                                   $
                                   $       EID     CAERO   ID1     ID2     SETG    DZ      DTOR    CID     +SPL
                                   SPLINE2 1001    1001    1001    1091    1001    0.0     1.0     1       +SPL1
                                   $+SPL   DTHX    DTHY
                                   +SPL1   -1.0    -1.0
                                   $
                                   SPLINE2 2001    1001    1002    1092    2001    0.0     1.0     2       +SPL2
                                   +SPL2   -1.0    -1.0
                                   SPLINE2 3001    1001    1003    1093    3001    0.0     1.0     3       +SPL3
                                   +SPL3   -1.0    -1.0
                                   SPLINE2 4001    1001    1004    1094    4001    0.0     1.0     4       +SPL4
                                   +SPL4   -1.0    -1.0
                                   SPLINE2 5001    1001    1005    1095    5001    0.0     1.0     5       +SPL5
                                   +SPL5   -1.0    -1.0
                                   SPLINE2 6001    1001    1006    1096    6001    0.0     1.0     6       +SPL6
                                   +SPL6   -1.0    -1.0
                                   SPLINE2 7001    1001    1007    1097    7001    0.0     1.0     7       +SPL7
                                   +SPL7   -1.0    -1.0
                                   SPLINE2 8001    1001    1008    1098    8001    0.0     1.0     8       +SPL8
                                   +SPL8   -1.0    -1.0
                                   SPLINE2 9001    1001    1009    1099    9001    0.0     1.0     9       +SPL9
                                   +SPL9   -1.0    -1.0
                                   SPLINE2 10001   1001    1010    1100    10001   0.0     1.0     10      +SPL10
                                   +SPL10  -1.0    -1.0
```

Listing 8-33 Input Data for Flutter Analysis of Square Panel Using ZONA51 Aerodynamics (Continued)

```
$
$       SID     G1      G2      G3      ETC
SET1    1001    1       THRU    22
SET1    2001    12      THRU    33
SET1    3001    23      THRU    44
SET1    4001    34      THRU    55
SET1    5001    45      THRU    66
SET1    6001    56      THRU    77
SET1    7001    67      THRU    88
SET1    8001    78      THRU    99
SET1    9001    89      THRU    110
SET1    10001   100     THRU    121
$
$       CID     RID     A1      A2      A3      B1      B2      B3      +CRD
CORD2R  1               0.5     0.0     0.0     0.5     0.0     1.0     +CRD1
$       C1      C2      C3
+CRD1   20.0    0.0     0.0
CORD2R  2               1.5     0.0     0.0     1.5     0.0     1.0     +CRD2
+CRD2   20.0    0.0     0.0
CORD2R  3               2.5     0.0     0.0     2.5     0.0     1.0     +CRD3
+CRD3   20.0    0.0     0.0
CORD2R  4               3.5     0.0     0.0     3.5     0.0     1.0     +CRD4
+CRD4   20.0    0.0     0.0
CORD2R  5               4.5     0.0     0.0     4.5     0.0     1.0     +CRD5
+CRD5   20.0    0.0     0.0
CORD2R  6               5.5     0.0     0.0     5.5     0.0     1.0     +CRD6
+CRD6   20.0    0.0     0.0
CORD2R  7               6.5     0.0     0.0     6.5     0.0     1.0     +CRD7
+CRD7   20.0    0.0     0.0
CORD2R  8               7.5     0.0     0.0     7.5     0.0     1.0     +CRD8
+CRD8   20.0    0.0     0.0
CORD2R  9               8.5     0.0     0.0     8.5     0.0     1.0     +CRD9
+CRD9   20.0    0.0     0.0
CORD2R  10              9.5     0.0     0.0     9.5     0.0     1.0     +CRD10
+CRD10  20.0    0.0     0.0
$
AERO    0       0       10.0    1.1468-7
$
$       M1      M2      ETC                                             +MK
MKAERO1 2.0     3.0                                                     +MK
$       K1      K2      K3      ETC
+MK     0.001   0.1     0.2     0.4
$
FLUTTER 30      PK      1       2       3               4
FLFACT  1       0.5
FLFACT  2       2.0     3.0
FLFACT  3       21600.  22200.  22800.  24000.  26400.  28800.  29400.  +FL3
+FL3    30000.  31200.
$
PARAM   VREF    12.0
$
EIGR    20      AGIV    0.      1000.           15                      +ER
+ER     MAX
$
$PARAM  LMODES  10
$
PARAM   OPPHIPA 1
$
ENDDATA
INPUT BULK DATA CARD COUNT =     191
```

Listing 8-34 Sorted Bulk Data for Flutter Analysis of Square Panel Using ZONA51 Aerodynamics

```
3D PANEL FLUTTER                                                                                          PAGE    11
 PINNED EDGES
 ZONA51 AERO, EXAMPLE HA145HB
                                             S O R T E D   B U L K   D A T A   E C H O
           CARD
           COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
              1-        AERO    0       0       10.0    1.1468-7
              2-        CAERO1  1001    1       0       10      10                      1       +CA1
              3-        +CA1    0.0     0.0     0.0     10.0    0.0     10.0    0.0     10.0
              4-        CAERO1  2001    1       0       10      10                      1       +CA2
              5-        +CA2    0.0     -10.0   0.0     10.0    0.0     0.0     0.0     10.0
              6-        CAERO1  3001    1       0       10      10                      1       +CA3
              7-        +CA3    0.0     10.0    0.0     10.0    0.0     20.0    0.0     10.0
              8-        CORD2R  1               0.5     0.0     0.0     0.5     0.0     1.0     +CRD1
              9-        +CRD1   20.0    0.0     0.0
             10-        CORD2R  2               1.5     0.0     0.0     1.5     0.0     1.0     +CRD2
             11-        +CRD2   20.0    0.0     0.0
             12-        CORD2R  3               2.5     0.0     0.0     2.5     0.0     1.0     +CRD3
             13-        +CRD3   20.0    0.0     0.0
             14-        CORD2R  4               3.5     0.0     0.0     3.5     0.0     1.0     +CRD4
             15-        +CRD4   20.0    0.0     0.0
             16-        CORD2R  5               4.5     0.0     0.0     4.5     0.0     1.0     +CRD5
             17-        +CRD5   20.0    0.0     0.0
             18-        CORD2R  6               5.5     0.0     0.0     5.5     0.0     1.0     +CRD6
             19-        +CRD6   20.0    0.0     0.0
             20-        CORD2R  7               6.5     0.0     0.0     6.5     0.0     1.0     +CRD7
             21-        +CRD7   20.0    0.0     0.0
             22-        CORD2R  8               7.5     0.0     0.0     7.5     0.0     1.0     +CRD8
             23-        +CRD8   20.0    0.0     0.0
             24-        CORD2R  9               8.5     0.0     0.0     8.5     0.0     1.0     +CRD9
             25-        +CRD9   20.0    0.0     0.0
             26-        CORD2R  10              9.5     0.0     0.0     9.5     0.0     1.0     +CRD10
             27-        +CRD10  20.0    0.0     0.0
             28-        CQUAD4  1       1       1       2       13      12
             29-        CQUAD4  2       1       2       3       14      13
             30-        CQUAD4  3       1       3       4       15      14
             31-        CQUAD4  4       1       4       5       16      15
             32-        CQUAD4  5       1       5       6       17      16
             33-        CQUAD4  6       1       6       7       18      17
             34-        CQUAD4  7       1       7       8       19      18
             35-        CQUAD4  8       1       8       9       20      19
             36-        CQUAD4  9       1       9       10      21      20
             37-        CQUAD4  10      1       10      11      22      21
             38-        CQUAD4  11      1       12      13      24      23
             39-        CQUAD4  12      1       13      14      25      24
             40-        CQUAD4  13      1       14      15      26      25
             41-        CQUAD4  14      1       15      16      27      26
             42-        CQUAD4  15      1       16      17      28      27
             43-        CQUAD4  16      1       17      18      29      28
             44-        CQUAD4  17      1       18      19      30      29
             45-        CQUAD4  18      1       19      20      31      30
             46-        CQUAD4  19      1       20      21      32      31
             47-        CQUAD4  20      1       21      22      33      32
             48-        CQUAD4  21      1       23      24      35      34
             49-        CQUAD4  22      1       24      25      36      35
             50-        CQUAD4  23      1       25      26      37      36
             51-        CQUAD4  24      1       26      27      38      37
             52-        CQUAD4  25      1       27      28      39      38
             53-        CQUAD4  26      1       28      29      40      39
             54-        CQUAD4  27      1       29      30      41      40
             55-        CQUAD4  28      1       30      31      42      41
             56-        CQUAD4  29      1       31      32      43      42
             57-        CQUAD4  30      1       32      33      44      43
             58-        CQUAD4  31      1       34      35      46      45
             59-        CQUAD4  32      1       35      36      47      46
             60-        CQUAD4  33      1       36      37      48      47
             61-        CQUAD4  34      1       37      38      49      48
             62-        CQUAD4  35      1       38      39      50      49
             63-        CQUAD4  36      1       39      40      51      50
             64-        CQUAD4  37      1       40      41      52      51
             65-        CQUAD4  38      1       41      42      53      52
             66-        CQUAD4  39      1       42      43      54      53
             67-        CQUAD4  40      1       43      44      55      54
             68-        CQUAD4  41      1       45      46      57      56
             69-        CQUAD4  42      1       46      47      58      57
             70-        CQUAD4  43      1       47      48      59      58
             71-        CQUAD4  44      1       48      49      60      59
             72-        CQUAD4  45      1       49      50      61      60
             73-        CQUAD4  46      1       50      51      62      61
             74-        CQUAD4  47      1       51      52      63      62
             75-        CQUAD4  48      1       52      53      64      63
```

Listing 8-34 Sorted Bulk Data for Flutter Analysis of Square Panel Using ZONA51 Aerodynamics (Continued)

```
CQUAD4  49      1       53      54      65      64
CQUAD4  50      1       54      55      66      65
CQUAD4  51      1       56      57      68      67
CQUAD4  52      1       57      58      69      68
CQUAD4  53      1       58      59      70      69
CQUAD4  54      1       59      60      71      70
CQUAD4  55      1       60      61      72      71
CQUAD4  56      1       61      62      73      72
CQUAD4  57      1       62      63      74      73
CQUAD4  58      1       63      64      75      74
CQUAD4  59      1       64      65      76      75
CQUAD4  60      1       65      66      77      76
CQUAD4  61      1       67      68      79      78
CQUAD4  62      1       68      69      80      79
CQUAD4  63      1       69      70      81      80
CQUAD4  64      1       70      71      82      81
CQUAD4  65      1       71      72      83      82
CQUAD4  66      1       72      73      84      83
CQUAD4  67      1       73      74      85      84
CQUAD4  68      1       74      75      86      85
CQUAD4  69      1       75      76      87      86
CQUAD4  70      1       76      77      88      87
CQUAD4  71      1       78      79      90      89
CQUAD4  72      1       79      80      91      90
CQUAD4  73      1       80      81      92      91
CQUAD4  74      1       81      82      93      92
CQUAD4  75      1       82      83      94      93
CQUAD4  76      1       83      84      95      94
CQUAD4  77      1       84      85      96      95
CQUAD4  78      1       85      86      97      96
CQUAD4  79      1       86      87      98      97
CQUAD4  80      1       87      88      99      98
CQUAD4  81      1       89      90      101     100
CQUAD4  82      1       90      91      102     101
CQUAD4  83      1       91      92      103     102
CQUAD4  84      1       92      93      104     103
CQUAD4  85      1       93      94      105     104
CQUAD4  86      1       94      95      106     105
CQUAD4  87      1       95      96      107     106
CQUAD4  88      1       96      97      108     107
CQUAD4  89      1       97      98      109     108
CQUAD4  90      1       98      99      110     109
CQUAD4  91      1       100     101     112     111
CQUAD4  92      1       101     102     113     112
CQUAD4  93      1       102     103     114     113
CQUAD4  94      1       103     104     115     114
CQUAD4  95      1       104     105     116     115
CQUAD4  96      1       105     106     117     116
CQUAD4  97      1       106     107     118     117
CQUAD4  98      1       107     108     119     118
CQUAD4  99      1       108     109     120     119
CQUAD4  100     1       109     110     121     120
EIGR    20      AGIV    0.      1000.           15                      +ER
+ER     MAX
FLFACT  1       0.5
FLFACT  2       2.0     3.0
FLFACT  3       21600.  22200.  22800.  24000.  26400.  28800.  29400.  +FL3
+FL3    30000.  31200.
FLUTTER 30      PK      1       2       3               4
GRID    1               0.0     0.0     0.0
GRID    2               0.0     1.0     0.0
GRID    3               0.0     2.0     0.0
GRID    4               0.0     3.0     0.0
GRID    5               0.0     4.0     0.0
GRID    6               0.0     5.0     0.0
GRID    7               0.0     6.0     0.0
GRID    8               0.0     7.0     0.0
GRID    9               0.0     8.0     0.0
GRID    10              0.0     9.0     0.0
GRID    11              0.0     10.0    0.0
GRID    12              1.0     0.0     0.0
GRID    13              1.0     1.0     0.0
GRID    14              1.0     2.0     0.0
GRID    15              1.0     3.0     0.0
GRID    16              1.0     4.0     0.0
GRID    17              1.0     5.0     0.0
GRID    18              1.0     6.0     0.0
GRID    19              1.0     7.0     0.0
GRID    20              1.0     8.0     0.0
GRID    21              1.0     9.0     0.0
GRID    22              1.0     10.0    0.0
GRID    23              2.0     0.0     0.0
GRID    24              2.0     1.0     0.0
GRID    25              2.0     2.0     0.0
```

Listing 8-34 Sorted Bulk Data for Flutter Analysis of Square Panel Using ZONA51 Aerodynamics (Continued)

```
160-        GRID    26              2.0     3.0     0.0
161-        GRID    27              2.0     4.0     0.0
162-        GRID    28              2.0     5.0     0.0
163-        GRID    29              2.0     6.0     0.0
164-        GRID    30              2.0     7.0     0.0
165-        GRID    31              2.0     8.0     0.0
166-        GRID    32              2.0     9.0     0.0
167-        GRID    33              2.0     10.0    0.0
168-        GRID    34              3.0     0.0     0.0
169-        GRID    35              3.0     1.0     0.0
170-        GRID    36              3.0     2.0     0.0
171-        GRID    37              3.0     3.0     0.0
172-        GRID    38              3.0     4.0     0.0
173-        GRID    39              3.0     5.0     0.0
174-        GRID    40              3.0     6.0     0.0
175-        GRID    41              3.0     7.0     0.0
176-        GRID    42              3.0     8.0     0.0
177-        GRID    43              3.0     9.0     0.0
178-        GRID    44              3.0     10.0    0.0
179-        GRID    45              4.0     0.0     0.0
180-        GRID    46              4.0     1.0     0.0
181-        GRID    47              4.0     2.0     0.0
182-        GRID    48              4.0     3.0     0.0
183-        GRID    49              4.0     4.0     0.0
184-        GRID    50              4.0     5.0     0.0
185-        GRID    51              4.0     6.0     0.0
186-        GRID    52              4.0     7.0     0.0
187-        GRID    53              4.0     8.0     0.0
188-        GRID    54              4.0     9.0     0.0
189-        GRID    55              4.0     10.0    0.0
190-        GRID    56              5.0     0.0     0.0
191-        GRID    57              5.0     1.0     0.0
192-        GRID    58              5.0     2.0     0.0
193-        GRID    59              5.0     3.0     0.0
194-        GRID    60              5.0     4.0     0.0
195-        GRID    61              5.0     5.0     0.0
196-        GRID    62              5.0     6.0     0.0
197-        GRID    63              5.0     7.0     0.0
198-        GRID    64              5.0     8.0     0.0
199-        GRID    65              5.0     9.0     0.0
200-        GRID    66              5.0     10.0    0.0
201-        GRID    67              6.0     0.0     0.0
202-        GRID    68              6.0     1.0     0.0
203-        GRID    69              6.0     2.0     0.0
204-        GRID    70              6.0     3.0     0.0
205-        GRID    71              6.0     4.0     0.0
206-        GRID    72              6.0     5.0     0.0
207-        GRID    73              6.0     6.0     0.0
208-        GRID    74              6.0     7.0     0.0
209-        GRID    75              6.0     8.0     0.0
210-        GRID    76              6.0     9.0     0.0
211-        GRID    77              6.0     10.0    0.0
212-        GRID    78              7.0     0.0     0.0
213-        GRID    79              7.0     1.0     0.0
214-        GRID    80              7.0     2.0     0.0
215-        GRID    81              7.0     3.0     0.0
216-        GRID    82              7.0     4.0     0.0
217-        GRID    83              7.0     5.0     0.0
218-        GRID    84              7.0     6.0     0.0
219-        GRID    85              7.0     7.0     0.0
220-        GRID    86              7.0     8.0     0.0
221-        GRID    87              7.0     9.0     0.0
222-        GRID    88              7.0     10.0    0.0
223-        GRID    89              8.0     0.0     0.0
224-        GRID    90              8.0     1.0     0.0
225-        GRID    91              8.0     2.0     0.0
226-        GRID    92              8.0     3.0     0.0
227-        GRID    93              8.0     4.0     0.0
228-        GRID    94              8.0     5.0     0.0
229-        GRID    95              8.0     6.0     0.0
230-        GRID    96              8.0     7.0     0.0
231-        GRID    97              8.0     8.0     0.0
232-        GRID    98              8.0     9.0     0.0
233-        GRID    99              8.0     10.0    0.0
234-        GRID    100             9.0     0.0     0.0
235-        GRID    101             9.0     1.0     0.0
236-        GRID    102             9.0     2.0     0.0
237-        GRID    103             9.0     3.0     0.0
238-        GRID    104             9.0     4.0     0.0
239-        GRID    105             9.0     5.0     0.0
240-        GRID    106             9.0     6.0     0.0
241-        GRID    107             9.0     7.0     0.0
242-        GRID    108             9.0     8.0     0.0
243-        GRID    109             9.0     9.0     0.0
244-        GRID    110             9.0     10.0    0.0
245-        GRID    111             10.0    0.0     0.0
```

Listing 8-34 Sorted Bulk Data for Flutter Analysis of Square Panel Using ZONA51 Aerodynamics (Continued)

```
GRID    112             10.0    1.0     0.0
GRID    113             10.0    2.0     0.0
GRID    114             10.0    3.0     0.0
GRID    115             10.0    4.0     0.0
GRID    116             10.0    5.0     0.0
GRID    117             10.0    6.0     0.0
GRID    118             10.0    7.0     0.0
GRID    119             10.0    8.0     0.0
GRID    120             10.0    9.0     0.0
GRID    121             10.0    10.0    0.0
MAT1    10      1.03+7  3.9+6           .1
MKAERO1 2.0     3.0                                                     +MK
+MK     0.001   0.1     0.2     0.4
PAERO1  1
PARAM   COUPMASS1
PARAM   GRDPNT  1
PARAM   OPPHIPA 1
PARAM   VREF    12.0
PARAM   WTMASS  .0025907
PSHELL  1       10      .041    10
SET1    1001    1       THRU    22
SET1    2001    12      THRU    33
SET1    3001    23      THRU    44
SET1    4001    34      THRU    55
SET1    5001    45      THRU    66
SET1    6001    56      THRU    77
SET1    7001    67      THRU    88
SET1    8001    78      THRU    99
SET1    9001    89      THRU    110
SET1    10001   100     THRU    121
SPC1    1       1       1
SPC1    1       2       1       110
SPC1    1       3       1       THRU    11
SPC1    1       3       12      22      23      33      34      44      +SP1
+SP1    45      55      56      66      67      77      78      88      +SP2
+SP2    89      99      100     110
SPC1    1       3       111     THRU    121
SPC1    1       6       1       THRU    121
SPLINE2 1001    1001    1001    1091    1001    0.0     1.0     1       +SPL1
+SPL1   -1.0    -1.0
SPLINE2 2001    1001    1002    1092    2001    0.0     1.0     2       +SPL2
+SPL2   -1.0    -1.0
SPLINE2 3001    1001    1003    1093    3001    0.0     1.0     3       +SPL3
+SPL3   -1.0    -1.0
SPLINE2 4001    1001    1004    1094    4001    0.0     1.0     4       +SPL4
+SPL4   -1.0    -1.0
SPLINE2 5001    1001    1005    1095    5001    0.0     1.0     5       +SPL5
+SPL5   -1.0    -1.0
SPLINE2 6001    1001    1006    1096    6001    0.0     1.0     6       +SPL6
+SPL6   -1.0    -1.0
SPLINE2 7001    1001    1007    1097    7001    0.0     1.0     7       +SPL7
+SPL7   -1.0    -1.0
SPLINE2 8001    1001    1008    1098    8001    0.0     1.0     8       +SPL8
+SPL8   -1.0    -1.0
SPLINE2 9001    1001    1009    1099    9001    0.0     1.0     9       +SPL9
+SPL9   -1.0    -1.0
SPLINE2 10001   1001    1010    1100    10001   0.0     1.0     10      +SPL10
+SPL10  -1.0    -1.0
ENDDATA
TOTAL COUNT=    304
```

Listing 8-35 Output from Flutter Analysis of Square Panel Using ZONA51 Aerodynamics

```
3D PANEL FLUTTER                                                                                   PAGE   168
 PINNED EDGES

 ZONA51 AERO, EXAMPLE HA145HB

                                                FLUTTER  SUMMARY

  POINT =     1     MACH NUMBER =  2.0000     DENSITY RATIO =  5.0000E-01     METHOD = PK
  KFREQ          1./KFREQ         VELOCITY          DAMPING          FREQUENCY            COMPLEX   EIGENVALUE
   0.2002      4.9941931E+00    1.8000000E+03    -1.5295196E-01    1.3766975E+02    -6.6152077E+01    8.6500464E+02
   0.2116      4.7267179E+00    1.8500000E+03    -1.6892217E-01    1.4950076E+02    -7.9337761E+01    9.3934100E+02
   0.2205      4.5343862E+00    1.9000000E+03    -2.9962501E-01    1.6005396E+02    -1.5065875E+02    1.0056487E+03
   0.2183      4.5802159E+00    2.0000000E+03    -4.7017121E-01    1.6679207E+02    -2.4636630E+02    1.0479855E+03
   0.2138      4.6775627E+00    2.2000000E+03    -6.4868200E-01    1.7965297E+02    -3.6611383E+02    1.1287930E+03
   0.2121      4.7153649E+00    2.4000000E+03    -7.4875242E-01    1.9441389E+02    -4.5731497E+02    1.2215386E+03
   0.2121      4.7157297E+00    2.4500000E+03    -7.6651222E-01    1.9844882E+02    -4.7787851E+02    1.2468907E+03
   0.2122      4.7127347E+00    2.5000000E+03    -7.8205627E-01    2.0262749E+02    -4.9783594E+02    1.2731461E+03
   0.2129      4.6973310E+00    2.6000000E+03    -8.0754602E-01    2.1142363E+02    -5.3637769E+02    1.3284139E+03

  POINT =     2     MACH NUMBER =  2.0000     DENSITY RATIO =  5.0000E-01     METHOD = PK

  KFREQ          1./KFREQ         VELOCITY          DAMPING          FREQUENCY            COMPLEX   EIGENVALUE
   0.2595      3.8529315E+00    1.8000000E+03    -7.3716998E-02    1.7844838E+02    -4.1326641E+01    1.1212242E+03
   0.2424      4.1252098E+00    1.8500000E+03    -5.8460318E-02    1.7129987E+02    -3.1460678E+01    1.0763088E+03
   0.2284      4.3790030E+00    1.9000000E+03     6.9779575E-02    1.6573328E+02     3.6331882E+01    1.0413329E+03
   0.2222      4.5012388E+00    2.0000000E+03     2.3505199E-01    1.6971854E+02     1.2532655E+02    1.0663730E+03
   0.2162      4.6263223E+00    2.2000000E+03     4.0527347E-01    1.8164279E+02     2.3126837E+02    1.1412954E+03
   0.2141      4.6713800E+00    2.4000000E+03     4.9942601E-01    1.9624445E+02     3.0790619E+02    1.2330403E+03
   0.2140      4.6723228E+00    2.4500000E+03     5.1601660E-01    2.0029247E+02     3.2469693E+02    1.2584747E+03
   0.2142      4.6695371E+00    2.5000000E+03     5.3050166E-01    2.0450198E+02     3.4082715E+02    1.2849240E+03
   0.2149      4.6535463E+00    2.6000000E+03     5.5418670E-01    2.1341290E+02     3.7155801E+02    1.3409128E+03

  POINT =     3     MACH NUMBER =  2.0000     DENSITY RATIO =  5.0000E-01     METHOD = PK

  KFREQ          1./KFREQ         VELOCITY          DAMPING          FREQUENCY            COMPLEX   EIGENVALUE
   0.2841      3.5204258E+00    1.8000000E+03    -1.1996645E-01    1.9530289E+02    -7.3606873E+01    1.2271243E+03
   0.2778      3.6000168E+00    1.8500000E+03    -1.2269000E-01    1.9629016E+02    -7.5658478E+01    1.2333275E+03
   0.2721      3.6753762E+00    1.9000000E+03    -1.2527983E-01    1.9746184E+02    -7.7716675E+01    1.2406893E+03
   0.2624      3.8116384E+00    2.0000000E+03    -1.3001584E-01    2.0042395E+02    -8.1864525E+01    1.2593009E+03
   0.2492      4.0133109E+00    2.2000000E+03    -1.3746606E-01    2.0938774E+02    -9.0426689E+01    1.3156221E+03
   0.2445      4.0898609E+00    2.4000000E+03    -1.4209375E-01    2.2414758E+02    -1.0005964E+02    1.4083608E+03
   0.2450      4.0820804E+00    2.4500000E+03    -1.4296828E-01    2.2925346E+02    -1.0296876E+02    1.4404420E+03
   0.2464      4.0586076E+00    2.5000000E+03    -1.4400871E-01    2.3528502E+02    -1.0644688E+02    1.4783395E+03
   0.2552      3.9187410E+00    2.6000000E+03    -1.5543495E-01    2.5343005E+02    -1.2375327E+02    1.5923480E+03

  POINT =     4     MACH NUMBER =  2.0000     DENSITY RATIO =  5.0000E-01     METHOD = PK

  KFREQ          1./KFREQ         VELOCITY          DAMPING          FREQUENCY            COMPLEX   EIGENVALUE
   0.4462      2.2409444E+00    1.8000000E+03    -6.8533927E-02    3.0681232E+02    -6.6058441E+01    1.9277588E+03
   0.4331      2.3091853E+00    1.8500000E+03    -7.0626095E-02    3.0601611E+02    -6.7898376E+01    1.9227560E+03
   0.4205      2.3780580E+00    1.9000000E+03    -7.2728880E-02    3.0518454E+02    -6.9729942E+01    1.9175311E+03
   0.3971      2.5180054E+00    2.0000000E+03    -7.6967016E-02    3.0339240E+02    -7.3359985E+01    1.9062708E+03
   0.3558      2.8103240E+00    2.2000000E+03    -8.5559450E-02    2.9901825E+02    -8.0373993E+01    1.8787871E+03
   0.3189      3.1355634E+00    2.4000000E+03    -9.4068855E-02    2.9236609E+02    -8.6401794E+01    1.8369905E+03
   0.3098      3.2280867E+00    2.4500000E+03    -9.6002229E-02    2.8990268E+02    -8.7434624E+01    1.8215123E+03
   0.3003      3.3298919E+00    2.5000000E+03    -9.7581819E-02    2.8677496E+02    -8.7914406E+01    1.8018604E+03
   0.2772      3.6080966E+00    2.6000000E+03    -9.0925038E-02    2.7524948E+02    -7.8624863E+01    1.7294436E+03

  POINT =     5     MACH NUMBER =  3.0000     DENSITY RATIO =  5.0000E-01     METHOD = PK

  KFREQ          1./KFREQ         VELOCITY          DAMPING          FREQUENCY            COMPLEX   EIGENVALUE
   0.1455      6.8719449E+00    1.8000000E+03    -1.3304967E-01    1.0005164E+02    -4.1820374E+01    6.2864301E+02
   0.1454      6.8773971E+00    1.8500000E+03    -1.3403367E-01    1.0274933E+02    -4.3265602E+01    6.4559308E+02
   0.1456      6.8678694E+00    1.9000000E+03    -1.3483095E-01    1.0567273E+02    -4.4761272E+01    6.6396136E+02
   0.1470      6.8046999E+00    2.0000000E+03    -1.3596269E-01    1.1226706E+02    -4.7953690E+01    7.0539478E+02
   0.1539      6.4970131E+00    2.2000000E+03    -1.3780704E-01    1.2934222E+02    -5.5996593E+01    8.1268115E+02
   0.1737      5.7577105E+00    2.4000000E+03    -1.8923114E-01    1.5921822E+02    -9.4653191E+01    1.0003976E+03
   0.1764      5.6676235E+00    2.4500000E+03    -2.8943378E-01    1.6511876E+02    -1.5013969E+02    1.0374718E+03
   0.1760      5.6815982E+00    2.5000000E+03    -3.6082676E-01    1.6807413E+02    -1.9052391E+02    1.0560409E+03
   0.1743      5.7366500E+00    2.6000000E+03    -4.6060652E-01    1.7311963E+02    -2.5051071E+02    1.0877428E+03
```

Listing 8-35 Output from Flutter Analysis of Square Panel Using ZONA51 Aerodynamics (Continued)

```
POINT =    6     MACH NUMBER =  3.0000     DENSITY RATIO =  5.0000E-01     METHOD = PK

KFREQ          1./KFREQ        VELOCITY          DAMPING          FREQUENCY           COMPLEX   EIGENVALUE
 0.2854      3.5038400E+00   1.8000000E+03   -5.6072671E-02    1.9622739E+02    -3.4566925E+01     1.2329331E+03
 0.2769      3.6108031E+00   1.8500000E+03   -5.7603832E-02    1.9570380E+02    -3.5416084E+01     1.2296433E+03
 0.2688      3.7197495E+00   1.9000000E+03   -5.9102427E-02    1.9510628E+02    -3.6226505E+01     1.2258889E+03
 0.2535      3.9454696E+00   2.0000000E+03   -6.1949197E-02    1.9362553E+02    -3.7683239E+01     1.2165852E+03
 0.2245      4.4543200E+00   2.2000000E+03   -6.5977067E-02    1.8865689E+02    -3.9103493E+01     1.1853662E+03
 0.1892      5.2855530E+00   2.4000000E+03   -1.8683814E-02    1.7344115E+02    -1.0180464E+01     1.0897629E+03
 0.1834      5.4533815E+00   2.4500000E+03    7.9316705E-02    1.7160564E+02     4.2760830E+01     1.0782301E+03
 0.1810      5.5237727E+00   2.5000000E+03    1.4844792E-01    1.7287634E+02     8.0623108E+01     1.0862141E+03
 0.1780      5.6180801E+00   2.6000000E+03    2.4399443E-01    1.7677335E+02     1.3550227E+02     1.1106997E+03

POINT =    7     MACH NUMBER =  3.0000     DENSITY RATIO =  5.0000E-01     METHOD = PK

KFREQ          1./KFREQ        VELOCITY          DAMPING          FREQUENCY           COMPLEX   EIGENVALUE
 0.2897      3.4520025E+00   1.8000000E+03   -7.4259356E-02    1.9917404E+02    -4.6465843E+01     1.2514475E+03
 0.2824      3.5412250E+00   1.8500000E+03   -7.6250061E-02    1.9954900E+02    -4.7801292E+01     1.2538033E+03
 0.2756      3.6290245E+00   1.9000000E+03   -7.8217961E-02    1.9998390E+02    -4.9141842E+01     1.2565360E+03
 0.2632      3.7997696E+00   2.0000000E+03   -8.2076333E-02    2.0104999E+02    -5.1840824E+01     1.2632344E+03
 0.2429      4.1175284E+00   2.2000000E+03   -8.9420311E-02    2.0408798E+02    -5.7332844E+01     1.2823226E+03
 0.2275      4.3949976E+00   2.4000000E+03   -9.6153036E-02    2.0858542E+02    -6.3008167E+01     1.3105809E+03
 0.2244      4.4568248E+00   2.4500000E+03   -9.7727045E-02    2.0997708E+02    -6.4466866E+01     1.3193250E+03
 0.2215      4.5153017E+00   2.5000000E+03   -9.9254772E-02    2.1148746E+02    -6.5945610E+01     1.3288149E+03
 0.2164      4.6215367E+00   2.6000000E+03   -1.0216923E-01    2.1489102E+02    -6.8974457E+01     1.3502002E+03

POINT =    8     MACH NUMBER =  3.0000     DENSITY RATIO =  5.0000E-01     METHOD = PK

KFREQ          1./KFREQ        VELOCITY          DAMPING          FREQUENCY           COMPLEX   EIGENVALUE
 0.4630      2.1599417E+00   1.8000000E+03   -3.8562585E-02    3.1831848E+02    -3.8563629E+01     2.0000541E+03
 0.4502      2.2210848E+00   1.8500000E+03   -3.9748330E-02    3.1815436E+02    -3.9728912E+01     1.9990229E+03
 0.4381      2.2823322E+00   1.9000000E+03   -4.0938303E-02    3.1798462E+02    -4.0896469E+01     1.9979563E+03
 0.4158      2.4051633E+00   2.0000000E+03   -4.3329265E-02    3.1762656E+02    -4.3236248E+01     1.9957065E+03
 0.3770      2.6523955E+00   2.2000000E+03   -4.8146792E-02    3.1682230E+02    -4.7921787E+01     1.9906533E+03
 0.3445      2.9023838E+00   2.4000000E+03   -5.2976876E-02    3.1585501E+02    -5.2568306E+01     1.9845756E+03
 0.3372      2.9654558E+00   2.4500000E+03   -5.4179590E-02    3.1557745E+02    -5.3714508E+01     1.9828318E+03
 0.3302      3.0288160E+00   2.5000000E+03   -5.5378061E-02    3.1528149E+02    -5.4851200E+01     1.9809722E+03
 0.3168      3.1565666E+00   2.6000000E+03   -5.7755798E-02    3.1462247E+02    -5.7086735E+01     1.9768313E+03
```

Estimation of Dynamic Stability Derivatives (Example HA145I)

The use of oscillatory aerodynamic theory for the estimation of dynamic stability derivatives has been demonstrated by Rodden and Giesing (1970) [Reference 48], and by Rodden, Bellinger, and Giesing (1984) [Reference 46]. The procedure demonstrated may be followed in MSC Nastran to obtain the generalized aerodynamic forces for rigid body motions via a DMAP ALTER in SOL 145. The present example uses the model from Example HA144D, after first repeating the derivation of Rodden (1987) [Reference 43] with corrections.

The theory of Rodden and Giesing (1970) [Reference 48] is outlined for use with MSC Nastran first for the case of symmetrical plunging and pitching. The definitions of the longitudinal stability derivatives are given in the equations for the lift coefficient

$$C_z = C_{z_0} + C_{z_\alpha}\alpha + C_{z_{\dot\alpha}}\frac{\dot\alpha\bar{c}}{2V} + C_{z_q}\frac{q\bar{c}}{2V} \tag{8-11}$$

and moment coefficient

$$C_m = C_{m_0} + C_{m_\alpha}\alpha + C_{m_{\dot\alpha}}\frac{\dot\alpha\bar{c}}{2V} + C_{m_q}\frac{q\bar{c}}{2V} \tag{8-12}$$

The intercept values C_{z_0} and C_{m_0} will be omitted from further discussion since they cannot be estimated from oscillatory theory. Complex oscillatory aerodynamic coefficients are related to the real coefficients in harmonic motion via

$$C_z = \mathrm{Re}(\bar{C}_z e^{i\omega t}) \tag{8-13}$$

and

$$C_m = \mathrm{Re}(\bar{C}_m e^{i\omega t}) \tag{8-14}$$

where Re( ) denotes the real part of ( ). Harmonic plunging with amplitude

$$h_0[\theta = 0, \alpha = \dot{h}/V = (h_0/V)\mathrm{Re}(i\omega e^{i\omega t})]$$

is then considered and (8-11) through (8-14) lead to

$$\bar{C}_z/h_0(2/\bar{c}) = ikC_{z_\alpha} - k^2 C_{z_{\dot{\alpha}}} \tag{8-15}$$

$$\bar{C}_m/h_0(2/\bar{c}) = ikC_{m_\alpha} - k^2 C_{m_{\dot{\alpha}}} \tag{8-16}$$

If harmonic pitching with amplitude

$$\alpha_0[\theta = \alpha = \alpha_0 \mathrm{Re}(e^{i\omega t})]$$

is next considered, (8-11) through (8-14) lead to

$$\bar{C}_z/\alpha_0 = C_{z_\alpha} + ik(C_{z_{\dot{\alpha}}} + C_{z_q}) \tag{8-17}$$

$$\bar{C}_m/\alpha_0 = C_{m_\alpha} + ik(C_{m_{\dot{\alpha}}} + C_{m_q}) \tag{8-18}$$

The relationship between the generalized aerodynamic force matrices and the longitudinal stability derivatives requires the following information: a reference wing area, S, the mean aerodynamic chord (M.A.C.), $\bar{c}$, a reference chord, c_r, for the reduced frequency, $k = \omega c_r/2V$, the plunge mode amplitude, h_0, and the pitch mode amplitude, α_0. These parameters allow nondimensionalizing the elements of the generalized aerodynamic influence matrices. For one (m,k) pair, the generalized influence matrix Q_{hh} due to rigid body plunge and pitch appears as

$$[Q_{hh}] = \begin{bmatrix} Q_{11} & Q_{12} \\ Q_{21} & Q_{22} \end{bmatrix} \tag{8-19}$$

The relationship of Q_{hh} to the complex coefficients $\bar{C}_z/h_0(2/\bar{c})$, $\bar{C}_m/h_0(2/\bar{c})$, $\bar{C}_z/\alpha_0$, and $\bar{C}_m/\alpha_0$ is indicated by the following equations:

$$\frac{\bar{C}_z}{h_0(2/\bar{c})} = \frac{Q_{11}}{h_0^2 S(2/\bar{c})} \tag{8-20}$$

$$\frac{\bar{C}_m}{h_0(2/\bar{c})} = \frac{Q_{21}}{\alpha_0 h_0 S\bar{c}(2/\bar{c})} \tag{8-21}$$

$$\frac{\bar{C}_z}{\alpha_0} = \frac{Q_{12}}{\alpha_0 h_0 S} \tag{8-22}$$

$$\frac{\bar{C}_m}{\alpha_0} = \frac{Q_{22}}{\alpha_0^2 S\bar{c}} \tag{8-23}$$

Substitution of (8-20) through (8-23) into Equations 5 through 10 of Rodden and Giesing (1970) [Reference 48] yields the final relationship between the Q_{hh} matrix elements and the stability derivatives.

$$C_{z_\alpha} = -\left(\frac{1}{\alpha_0 h_0 S}\right)\mathrm{Re}(Q_{12}) \tag{8-24}$$

$$= \left(\frac{b}{h_0^2 kS}\right)\mathrm{Im}(Q_{11}) \tag{8-25}$$

$$C_{m_\alpha} = -\left(\frac{1}{\alpha_0^2 S\bar{c}}\right)\mathrm{Re}(Q_{22}) \tag{8-26}$$

$$= -\left(\frac{b}{\alpha_0 h_0 kS\bar{c}}\right)\mathrm{Im}(Q_{21}) \tag{8-27}$$

$$C_{z_{\dot{\alpha}}} = -\left(\frac{2b}{\bar{c}}\right)\left(\frac{b}{h_0^2 k^2 S}\right)\mathrm{Re}(Q_{11}) \tag{8-28}$$

$$C_{m_{\dot{\alpha}}} = \left(\frac{2b}{\bar{c}}\right)\left(\frac{b}{\alpha_0 h_0 k^2 S\bar{c}}\right)\mathrm{Re}(Q_{21}) \tag{8-29}$$

$$C_{z_{\dot{\alpha}}} + C_{z_q} = \left(\frac{2b}{\bar{c}}\right)\left(\frac{1}{\alpha_0 h_0 kS}\right)\mathrm{Im}(Q_{12}) \tag{8-30}$$

$$C_{m_{\dot{\alpha}}} + C_{m_q} = \left(\frac{2b}{\bar{c}}\right)\left(\frac{1}{\alpha_0^2 kS\bar{c}}\right)\mathrm{Im}(Q_{22}) \tag{8-31}$$

where $b = c_r/2$ and Im( ) denotes the imaginary part of ( ).

The calculation of lateral-directional derivatives is similar to that for the longitudinal derivatives illustrated above. The derivation follows along the lines given by Rodden and Giesing (1970) [Reference 48] and the preceeding derivation.

The definitions of the lateral-directional stability derivatives are given in the equations for the side force coefficient

$$C_Y = C_{y_\beta}\beta + C_{Y_{\dot{\beta}}}\frac{\dot{\beta}b}{2V} + C_{Y_p}\frac{pb}{2V} + C_{Y_{\dot{p}}}\frac{\dot{p}b^2}{4V^2} + C_{Y_r}\frac{rb}{2V} \tag{8-32}$$

the rolling moment coefficient

$$C_l = C_{l_\beta}\beta + C_{l_{\dot{\beta}}}\frac{\dot{\beta}b}{2V} + C_{l_p}\frac{pb}{2V} + C_{l_{\dot{p}}}\frac{\dot{p}b^2}{4V^2} + C_{l_r}\frac{rb}{2V} \tag{8-33}$$

and the yawing moment coefficient

$$C_n = C_{n_\beta}\beta + C_{n_{\dot{\beta}}}\frac{\dot{\beta}b}{2V} + C_{n_p}\frac{pb}{2V} + C_{n_{\dot{p}}}\frac{\dot{p}b^2}{4V^2} + C_{n_r}\frac{rb}{2V} \tag{8-34}$$

Note: (8-32) through (8-34) include $\dot{p}$ -terms but not $\dot{r}$ -terms because the $\dot{p}$ -terms are first order in reduced freqency (k) but $\dot{r}$ -terms are second order in k. The higher-order solution of Rodden and Giesing (1970) [Reference 48] demonstrated the procedure to obtain the longitudinal second-order $\dot{q}$ -terms. Following this procedure in the lateral-directional case will lead to the $\dot{r}$ -terms.

Again assuming that there are harmonic motions, first sidesway

$$[\phi = \psi = 0, \beta = \dot{y}/V = (y_0/V)\mathrm{Re}(i\omega e^{i\omega t})]$$

then roll $[\beta = \psi = 0, p = \dot{\phi} = \phi_0 \mathrm{Re}(i\omega e^{i\omega t})]$

and, finally, yaw $[\phi = 0, \psi = -\beta = \psi_0 \mathrm{Re}(e^{i\omega t})]$, $r = \dot{\psi} = \psi_0 \mathrm{Re}(i\omega e^{i\omega t})$, in order to compare the lateral-directional stability derivatives in (8-32) through (8-34) to the elements of the MSC Nastran generalized aerodynamic force matrix QHHL that appears as

$$[Q_{hh}] = \begin{bmatrix} Q_{11} & Q_{12} & Q_{13} \\ Q_{21} & Q_{22} & Q_{23} \\ Q_{31} & Q_{32} & Q_{33} \end{bmatrix} \tag{8-35}$$

where the i-subscript of Q_{ij} denotes side force by $i = 1$, rolling moment by $i = 2$, and yawing moment by $i = 3$; the j-subscript of Q_{ij} denotes sideslip by $j = 1$, roll rate by $j = 2$, and yaw rate by $j = 3$. In the following, the amplitude of the lateral displacement is y_0, the amplitude of the bank angle is ϕ_0, and the amplitude of the yaw angle is ψ_0, and the reference span of the vehicle is b. The expressions for the derivatives are:

Sideslip Derivatives

$$C_{Y_\beta} = \left(\frac{c_r}{2y_0^2 kS}\right) \mathrm{Im}(Q_{11}) \tag{8-36}$$

$$= -\left(\frac{1}{y_0 \psi_0 S}\right) \mathrm{Re}(Q_{13}) \tag{8-37}$$

$$C_{Y_{\dot\beta}} = -\left(\frac{c_r^2}{2y_0^2 k^2 Sb}\right) \mathrm{Re}(Q_{11}) \tag{8-38}$$

$$C_{l_\beta} = \left(\frac{c_r}{2y_0 \phi_0 kSb}\right) \mathrm{Im}(Q_{21}) \tag{8-39}$$

$$= -\left(\frac{1}{\phi_0 \psi_0 Sb}\right) \mathrm{Re}(Q_{23}) \tag{8-40}$$

$$C_{l_{\dot\beta}} = -\left(\frac{c_r^2}{2y_0 \phi_0 k^2 Sb^2}\right) \mathrm{Re}(Q_{21}) \tag{8-41}$$

$$C_{n_\beta} = \left(\frac{c_r}{2y_0\psi_0 kSb}\right)\mathrm{Im}(Q_{31}) \tag{8-42}$$

$$= -\left(\frac{1}{\psi_0^2 Sb}\right)\mathrm{Re}(Q_{33}) \tag{8-43}$$

$$C_{n_{\dot\beta}} = -\left(\frac{c_r^2}{2y_0\psi_0 k^2 Sb^2}\right)\mathrm{Im}(Q_{31}) \tag{8-44}$$

Rolling Derivatives

$$C_{Y_p} = \left(\frac{c_r}{y_0\phi_0 kSb}\right)\mathrm{Im}(Q_{12}) \tag{8-45}$$

$$C_{Y_{\dot p}} = -\left(\frac{c_r^2}{y_0\phi_0 k^2 Sb^2}\right)\mathrm{Re}(Q_{12}) \tag{8-46}$$

$$C_{l_p} = \left(\frac{c_r}{\phi_0^2 kSb^2}\right)\mathrm{Im}(Q_{22}) \tag{8-47}$$

$$C_{l_{\dot p}} = -\left(\frac{c_r^2}{\phi_0^2 k^2 Sb^3}\right)\mathrm{Re}(Q_{22}) \tag{8-48}$$

$$C_{n_p} = \left(\frac{c_r}{\phi_0\psi_0 kSb^2}\right)\mathrm{Im}(Q_{32}) \tag{8-49}$$

$$C_{n_{\dot p}} = -\left(\frac{c_r^2}{\phi_0\psi_0 k^2 Sb^3}\right)\mathrm{Re}(Q_{32}) \tag{8-50}$$

Yawing Derivatives

$$C_{Y_r} = \left(\frac{c_r}{y_0\psi_0 kSb}\right)\mathrm{Im}(Q_{13}) + C_{Y_{\dot\beta}} \tag{8-51}$$

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$$C_{l_r} = \left(\frac{c_r}{\phi_0\psi_0 kSb^2}\right)\mathrm{Im}(Q_{23}) + C_{l_{\dot\beta}} \tag{8-52}$$

$$C_{n_r} = \left(\frac{c_r}{\psi_0^2 kSb^2}\right)\mathrm{Im}(Q_{33}) + C_{n_{\dot\beta}} \tag{8-53}$$

Note that the present calculation of dynamic stability derivatives from an oscillatory solution at only one reduced frequency does not permit obtaining the $\dot{r}$-derivatives.

The present example uses the model from Example HA144D, which is contained in the input file HA144D_MODEL.DAT and is shown in Listing 7-15. Since Example HA144D calculated stability derivatives with respect to NACA coordinates at GRID 90, it is necessary to force the center of gravity here to GRID 90 by adding the large weight CONM1 90 to GRID 90 chosen arbitrarily as 8.0×10^9 lbs. Furthermore, it is essential to align the rigid body modes with the NACA axes, and this is accomplished by assigning large principal moments of inertia to CONM1 90 in the amount of 1.0×10^{12} lb-in^2. With both the large weight and large moments of inertia added, the calculated rigid body modes will be motions relative to the NACA axes, and the generalized aerodynamic forces will lead to the desired stability derivatives.

The Bulk Data Section begins with the request INCLUDE HA144D_MODEL.DAT. The next entry is CONM1 90. This is followed by the AERO entry, which is only required here to prescribe the antisymmetric motion. Next, the MKAERO1 entry specifies the Mach Number $m = 0.9$ and the two low reduced frequencies $k = 0.001$ and 0.01; two frequencies are selected to illustrate the frequency dependence of the dynamic derivatives. The vibration analysis for the rigid body modes is performed by EIGR 10, which specifies the modified Givens method MGIV and requests only the three rigid body modes normalized on their maximum components. The PARAM,OPPHIPA,1 along with the DISP request in Case Control provides the modal output so that the amplitudes of the rigid body modes are displayed.

Case Control Commands

The Case Control Section begins with three title commands. It then requests ECHO = BOTH, SPC = 1 for the antisymmetric boundary condition, DISP = 25 for the SET 25 = 1 through 400 structural grid point displacements to be printed, and the vibration analysis METHOD = 10.

The Executive Control Section specifies 5 minutes CPU time, and the Flutter Solution Sequence SOL 145. Then it provides the Alter to print the generalized aerodynamic force matrix QHHL for the flight conditions listed on the MKAERO entry and to exit the execution.

Output

The input data are shown in Listing 8-36 and Listing 8-37. The output data required for the stability derivative calculations follow in Listing 8-38.

The first output shown is the eigenvalue analysis. The rigid body modes are of interest and their frequencies are exact rather than computed zeros because of the SUPORT entry in the input. The modal amplitudes are required in the stability derivative calculation, and they are found from the eigenvectors. It should be noted that the eigenvectors are in the basic coordinate system, so the signs of the roll and yaw angles must be reversed to obtain them in the reference (NACA) coordinate system for use in the stability derivative calculations. The first eigenvector is the sidesway mode, and its amplitude is $y_0 = 1.0$. The second eigenvector is the roll mode, and its amplitude is $\phi_0 = -0.06666667$. Finally, the third eigenvector is the yaw mode, and $\psi_0 = -0.05590732$. The final output shown is the matrix QHHL for the three rigid modes, as in (8-35), printed by columns for the two reduced frequencies: the first three columns correspond to the lower frequency, $k = 0.001$, and the last three columns are for $k = 0.01$. The generalized aerodynamic forces are summarized in Table 8-5.

Table 8-5 Complex Generalized Aerodynamic Forces for Antisymmetric Rigid Body Modes of Example HA144D

Force	k = 0.001	k = 0.01
Q_{11}	1.2752-05 - *i*2.8634-02	1.2748-03 - *i*2.8634-01
Q_{21}	-1.4758-05 + *i*3.4945-03	-1.4776-03 + *i*3.4947-02
Q_{31}	1.7980-05 - *i*2.3189-02	1.7977-03 - *i*2.3189-01
Q_{12}	-2.1631-05 - *i*4.2480-03	-2.1650-03 - *i*4.2464-02
Q_{22}	5.6038-05 - *i*5.9515-02	5.5982-03 - *i*5.9523-01
Q_{32}	-1.8804-05 - *i*3.1072-03	-1.8821-03 - *i*3.1060-02
Q_{13}	-8.0042+00 - *i*3.5915-02	-8.0034+00 - *i*3.5914-01
Q_{23}	9.7683-01 + *i*9.2522-03	9.7541-01 + *i*9.2577-02
Q_{33}	-6.4820+00 - *i*3.2783-02	-6.4807+00 - *i*3.2782-01

The reference geometry $c_r = 10.0$ ft, $b = 40.0$ ft, $S = 200$ sq. ft, and (8-36) through (8-53) lead to the desired stability derivatives. The results are summarized in Table 8-6. The frequency dependence of the derivatives is seen by comparing the columns for the two frequencies. The static solution in the last column is taken from Example HA144D and has no estimates for the dynamic derivatives, which can only be obtained by using the oscillatory aerodynamic theory.

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Table 8-6 Lateral-Directional Static and Dynamic Stability Derivatives for FSW Airplane

Derivative	Equation	Value for k = 0.001	Value for k = 0.01	Static Results
C_{Y_β}	(8-36)	-0.71585	-0.71585	
	(8-37)	-0.71584	-0.71577	-0.71584
$C_{Y_{\dot\beta}}$	(8-38)	-0.079700	-0.079675	-
C_{l_β}	(8-39)	-0.032761	-0.032763	
	(8-40)	-0.032761	-0.032713	-0.032761
$C_{l_{\dot\beta}}$	(8-41)	-0.034589	-0.034631	-
C_{n_β}	(8-42)	0.25924	0.25923	
	(8-43)	0.25923	0.25918	0.25923
$C_{n_{\dot\beta}}$	(8-44)	0.050251	0.050242	-
C_{Y_p}	(8-45)	0.079650	0.079620	0.079650
$C_{Y_{\dot p}}$	(8-46)	-0.10195	-0.10148	-
C_{l_p}	(8-47)	-0.41846	-0.41852	-0.41847
$C_{l_{\dot p}}$	(8-48)	-0.098504	-0.098406	-
C_{n_p}	(8-49)	-0.026053	-0.026042	-0.026052
$C_{n_{\dot p}}$	(8-50)	0.039415	0.039451	-
C_{Y_r}	(8-51)	0.72330	0.72331	0.72330
C_{l_r}	(8-52)	0.042985	0.042989	0.042986
C_{n_r}	(8-53)	-0.27751	-0.27751	-0.27751

Listing 8-36 Input Files for Estimation of Dynamic Stability Derivatives

```
 N A S T R A N    E X E C U T I V E    C O N T R O L    D E C K    E C H O


ID MSC, HA145H
$$$$$$$$  HANDBOOK FOR AEROELASTIC ANALYSIS EXAMPLE HA145H      $$$$$$$$
$                                                                      $
$       MODEL DESCRIPTION        30 DEG FORWARD SWEPT WING WITH        $
$                                AILERON, CANARD AND AFT SWEPT         $
$                                VERTICAL FIN AND RUDDER.              $
$                                BAR MODEL WITH DUMBBELL MASSES.       $
$                                                                      $
$       SOLUTION                 ANTISYMMETRIC STATIC STABILITY        $
$                                DERIVATIVE ANALYSIS USING DOUBLET-    $
$                                LATTICE AERODYNAMICS AT MACH 0.9.     $
$                                                                      $
$       OUTPUT                   RIGID BODY MODES AND OSCILLATORY      $
$                                AERODYNAMIC MATRIX QHHL.              $
$                                                                      $
$$$$$$$$                                                        $$$$$$$$
TIME 5 $ CPU TIME IN MINUTES
SOL 145 $ FLUTTER
COMPILE SUBDMAP=FLUTTER,SOUIN=MSCSOU,NOREF,NOLIST $ V68
ALTER 50  $ V68
MATPRN QHHL// $ PRINTS QHHL MATRIX
EXIT $
CEND


EXAMPLE HA145H: 30 DEG FWD SWEPT WING WITH CANARD & FIN                                                                PAGE     2
 ANTISYMMETRIC STABILITY DERIVATIVES

HALF-SPAN MODEL, RIGID SIDESWAY, ROLL, AND YAW MOTIONS

                              C A S E    C O N T R O L    D E C K    E C H O
            CARD
            COUNT
             1      TITLE = EXAMPLE HA145H: 30 DEG FWD SWEPT WING WITH CANARD & FIN
             2      SUBTI = ANTISYMMETRIC STABILITY DERIVATIVES
             3      LABEL = HALF-SPAN MODEL, RIGID SIDESWAY, ROLL, AND YAW MOTIONS
             4        ECHO    = BOTH
             5        SPC     = 1    $ ANTISYMMETRIC CONSTRAINTS
             6        SET 25  = 1 THRU 400
             7        DISP    = 25   $ PRINT GRID POINT DISPLACEMENTS
             8        METHOD  = 10
             9      BEGIN BULK
```

Listing 8-36 Input Files for Estimation of Dynamic Stability Derivatives (Continued)

```
EXAMPLE HA145H: 30 DEG FWD SWEPT WING WITH CANARD & FIN                                             PAGE     3
 ANTISYMMETRIC STABILITY DERIVATIVES

 HALF-SPAN MODEL, RIGID SIDESWAY, ROLL, AND YAW MOTIONS

                                   I N P U T   B U L K   D A T A   D E C K   E C H O

                         .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                         $                                                                        $
                         INCLUDE HA144D_MODEL.DAT
                         $                                                                        $
                         $                       * GRID POINT 90 MASS *                           $
                         $                                                                        $
                         $        THE CONM1 ENTRY DEFINES A CONCENTRATED MASS IN ITS GENERAL      $
                         $        FORM. IT DEFINES A 6*6 SYMMETRIC MASS MATRIX AT A GEOMETRIC     $
                         $        GRID POINT.  LISTED ARE THE ELEMENTS OF THE 3*3 MASS            $
                         $        PARTITION, THE 3*3 STATIC UNBALANCE PARTITION, AND THE 3*3      $
                         $        INERTIA PARTITION.  IN THIS CASE, A LARGE MASS, WITH LARGE      $
                         $        PRINCIPAL MOMENTS OF INERTIA, IS CHOSEN AT THE REFERENCE        $
                         $        POINT TO ALIGN THE COMPUTED MODES WITH THE REFERENCE NACA       $
                         $        COORDINATE SYSTEM.                                              $
                         $                                                                        $
                         $CONM1  EID     G       CID     M11     M21     M22     M31     M32     +M1
                         CONM1   90      90              8.+9            8.+9                    +M1
                         $+M1    M33     M41     M42     M43     M44     M51     M52     M53     +M2
                         +M1     8.+9                            1.+12                           +M2
                         $+M2    M54     M55     M61     M62     M63     M64     M65     M66
                         +M2             1.+12                                           1.+12
                         $                                                                        $
                         $                                                                        $

 $                     * * * AERODYNAMIC DATA * * *                    $
                              $                                                                        $
                              $                         (LB-FT-SEC SYSTEM)                             $
                              $                                                                        $
                              $        THE AERO ENTRY SPECIFIES THE AERO COORDINATE SYSTEM, THE        $
                              $        REFERENCE LENGTHS PLUS SYMMETRY KEYS.  SYMXZ = -1 INDICATES     $
                              $        ANTISYMMETRICAL MOTION.                                         $
                              $                                                                        $
                              $       ACSID   VELOCITY REFC   RHOREF  SYMXZ   SYMXY
                              AERO    1               10.0    2.378-3 -1
                              $
                              $                                                                        $
                              $                     * AERODYNAMIC CONDITIONS *                         $
                              $                                                                        $
                              $        ALL COMBINATIONS OF MACH NUMBER AND REDUCED FREQUENCY LISTED    $
                              $        ON THE MKAERO1 CARD AND ITS CONTINUATION CARD WILL BE USED      $
                              $        TO GENERATE GENERALIZED AERO FORCE MATRICES.                    $
                              $                                                                        $
                              MKAERO1 0.9                                                             +MK
                              +MK     0.001   0.01
                              $                                                                        $
                              $                 * * VIBRATION SOLUTION PARAMETERS * *                  $
                              $                                                                        $
                              $        THE EIGR ENTRY SPECIFIES THE METHOD OF EXTRACTING THE EIGEN-    $
                              $        SOLUTIONS OF THE STRUCTURE IN A VACUUM; IN THIS CASE THE        $
                              $        MODIFIED GIVENS METHOD.  THE THREE RIGID BODY MODES ARE         $
                              $        DESIRED, NORMALIZED ON THE MAXIMUM DISPLACEMENTS.               $
                              $                                                                        $
                              EIGR    10      MGIV                            3                       +IGR
                              +IGR    MAX
                              $
                              $        THE PARAM,OPPHIPA,1 PROVIDES THE VIBRATION MODES FOR THE        $
                              $        MODAL PRINT AND PLOT REQUESTS.                                  $
                              $                                                                        $
                              PARAM   OPPHIPA 1
                              ENDDATA

                              INPUT BULK DATA CARD COUNT =     398
```

Listing 8-37 Sorted Bulk Data for Estimation of Dynamic Stability Derivatives

```
EXAMPLE HA145I: 30 DEG FWD SWEPT WING WITH CANARD & FIN                                                      PAGE    12
  ANTISYMMETRIC STABILITY DERIVATIVES
 HALF-SPAN MODEL, RIGID SIDESWAY, ROLL, AND YAW MOTIONS
                                             S O R T E D   B U L K   D A T A   E C H O
             CARD
             COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
               1-        AELIST  2000    1119    1123    1127    1131
               2-        AELIST  3000    3103    3107    3111    3115
               3-        AERO    1               10.0    2.378-3 -1
               4-        AESURF  517     AILERON 110     2000
               5-        AESURF  518     RUDDER  301     3000
               6-        CAERO1  1000    1000            2       4                       1       +CAC
               7-        +CAC    10.     0.      0.      10.     10.     5.      0.      10.
               8-        CAERO1  1100    1000            8       4                       1       +CAW
               9-        +CAW    25.     0.      0.      10.     13.45299+20.    0.      10.
              10-        CAERO1  3100    1000            4       4                       1       +CA1FI
              11-        +CA1FI  30.7735 0.      10.     10.     25.     0.      0.      10.
              12-        CBAR    100     100     90      99      0.      0.      1.
              13-        CBAR    101     100     97      98      0.      0.      1.
              14-        CBAR    102     100     98      90      0.      0.      1.
              15-        CBAR    103     100     99      100     0.      0.      1.
              16-        CBAR    110     101     100     110     0.      0.      1.
              17-        CBAR    120     101     110     120     0.      0.      1.
              18-        CBAR    310     301     100     310     0.      0.      1.
              19-        CONM1   90      90              8.+9            8.+9                    +M1
              20-        +M1     8.+9                            1.+12                           +M2
              21-        +M2             1.+12                                           1.+12
              22-        CONM2   97      97      0       1500.0
              23-        CONM2   98      98      0       1500.0
              24-        CONM2   99      99      0       1500.0
              25-        CONM2   100     100     0       1500.0
              26-        CONM2   111     111     0       600.0
              27-        CONM2   112     112     0       400.0
              28-        CONM2   121     121     0       600.0
              29-        CONM2   122     122     0       400.0
              30-        CONM2   311     311     0       30.0
              31-        CONM2   312     312     0       20.0
              32-        CORD2R  1       0       12.5    0.      0.      12.5    0.      10.     +CRD1
              33-        +CRD1   20.     0.      0.
              34-        CORD2R  2       0       30.     0.      0.      30.     0.      10.     +CRD2
              35-        +CRD2   38.66025+5.0    0.
              36-        CORD2R  100     0       15.0    0.0     0.0     15.0    0.0     -10.0   +CRD100
              37-        +CRD100 0.0     0.0     0.0
              38-        CORD2R  110     0       26.7265 10.0    0.      26.7265 10.0    -10.0   +CRD2A
              39-        +CRD2A  36.7265 15.7735 0.
              40-        CORD2R  300     0       30.0    0.      0.      30.0    10.0    0.      +CRD2FI
              41-        +CRD2FI 20.0    0.      5.7735
              42-        CORD2R  301     0       32.5    0.      0.      32.5    -10.    0.0     +CRD2R
              43-        +CRD2R  22.5    0.      5.7735
              44-        EIGR    10      MGIV                            3                       +IGR
              45-        +IGR    MAX
              46-        GRID    90              15.     0.      0.
              47-        GRID    97              0.      0.      0.
              48-        GRID    98              10.     0.      0.
              49-        GRID    99              20.     0.      0.
              50-        GRID    100             30.     0.      0.
              51-        GRID    110             27.11325+5.     0.
              52-        GRID    111             24.61325+5.     0.
              53-        GRID    112             29.61325+5.     0.
              54-        GRID    120             21.33975+15.    0.
              55-        GRID    121             18.83975+15.    0.
              56-        GRID    122             23.83975+15.    0.
              57-        GRID    310             32.88675+0.     5.
              58-        GRID    311             30.38675+0.     5.
              59-        GRID    312             35.38675+0.     5.
              60-        MAT1    1       1.44+9  5.40+8
              61-        MKAERO1 0.9                                                     +MK
              62-        +MK     0.001   0.01
              63-        OMIT1   4       110     120     310
              64-        PAERO1  1000
              65-        PARAM   GRDPNT  90
              66-        PARAM   OPPHIPA 1
              67-        PARAM   WTMASS  .031081
```

Listing 8-37 Sorted Bulk Data for Estimation of Dynamic Stability Derivatives (Continued)

```
68-        PBAR    100     1       2.0     .173611 0.15    0.5                     +PB1F
69-        +PB1F   1.0     1.0     1.0     -1.0    -1.0    1.0     -1.0    -1.0    +PB2F
70-        +PB2F                   0.0

71-        PBAR    101     1       1.5     0.173611+2.0    0.462963                +PB1W
72-        +PB1W   0.5     3.0     0.5     -3.0    -0.5    3.0     -0.5    -3.0    +PB2W
73-        +PB2W                   0.0
74-        PBAR    301     1       .75     .086806 1.0     .231482                 +PB1FI
75-        +PB1FI  0.5     3.0     0.5     -3.0    -0.5    3.0     -0.5    -3.0    +PB2FI
76-        +PB2FI                  0.
77-        RBAR    111     110     111     123456
78-        RBAR    112     110     112     123456
79-        RBAR    121     120     121     123456
80-        RBAR    122     120     122     123456
81-        RBAR    311     310     311     123456
82-        RBAR    312     310     312     123456
83-        SET1    1000    98      99
84-        SET1    1100    99      100     111     112     121     122
85-        SET1    3100    99      100     311     312
86-        SPC1    1       35      97      98      99      100
87-        SPC1    1       135     90
88-        SPLINE2 1501    1000    1000    1007    1000    0.      1.      1       +SPC
89-        +SPC    1.      -1.
90-        SPLINE2 1601    1100    1100    1131    1100    0.      1.      2       +SPW
91-        +SPW    -1.     -1.
92-        SPLINE2 3100    3100    3100    3115    3100    0.      1.      300     +SP2FI
93-        +SP2FI  -1.     -1.
94-        SUPORT  90      246
           ENDDATA
     TOTAL COUNT=        95
```

Listing 8-38 Output for Estimation of Dynamic Stability Derivatives

```
EXAMPLE HA145H: 30 DEG FWD SWEPT WING WITH CANARD & FIN                                                    PAGE    21
 ANTISYMMETRIC STABILITY DERIVATIVES

 HALF-SPAN MODEL, RIGID SIDESWAY, ROLL, AND YAW MOTIONS

                                          R E A L   E I G E N V A L U E S
  MODE     EXTRACTION      EIGENVALUE            RADIANS             CYCLES            GENERALIZED         GENERALIZED
   NO.       ORDER                                                                        MASS              STIFFNESS
   1         3        0.0                 0.0                 0.0                 2.486483E+08        0.0
   2         2        0.0                 0.0                 0.0                 1.381378E+08        0.0
   3         1        0.0                 0.0                 0.0                 9.714776E+07        0.0
   4         4        1.189524E+03        3.448947E+01        5.489170E+00        0.0                 0.0
   5         5        1.512659E+03        3.889292E+01        6.190001E+00        0.0                 0.0
   6         7        4.028532E+03        6.347072E+01        1.010168E+01        0.0                 0.0
   7         6        7.604801E+03        8.720551E+01        1.387919E+01        0.0                 0.0
   8         8        6.609194E+04        2.570835E+02        4.091611E+01        0.0                 0.0
   9         9        1.532933E+05        3.915269E+02        6.231343E+01        0.0                 0.0
  10        12        2.790091E+05        5.282131E+02        8.406773E+01        0.0                 0.0

     EIGENVALUE =  0.000000E+00
     CYCLES =  0.000000E+00         R E A L   E I G E N V E C T O R   N O .         1

 POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
        90      G      0.0            1.000000E+00   0.0            0.0            0.0            0.0
        97      G      0.0            1.000000E+00   0.0            0.0            0.0            1.734723E-17
        98      G      0.0            1.000000E+00   0.0            0.0            0.0            2.602085E-18
        99      G      1.169039E-31   1.000000E+00   0.0           -5.659632E-17   0.0           -3.167247E-15
       100      G      3.507895E-31   1.000000E+00   0.0           -1.758605E-16   0.0           -4.518557E-15
       110      G      2.243618E-14   1.000000E+00  -9.020562E-16  -1.816386E-16   7.760559E-33  -4.460078E-15
       111      G      2.243618E-14   1.000000E+00  -9.020562E-16  -1.816386E-16   7.760559E-33  -4.460078E-15
       112      G      2.243618E-14   1.000000E+00  -9.020562E-16  -1.816386E-16   7.760559E-33  -4.460078E-15
       120      G      6.677991E-14   1.000000E+00  -2.706169E-15  -1.799392E-16   1.746126E-32  -4.419003E-15
       121      G      6.677991E-14   1.000000E+00  -2.706169E-15  -1.799392E-16   1.746126E-32  -4.419003E-15
       122      G      6.677991E-14   1.000000E+00  -2.706169E-15  -1.799392E-16   1.746126E-32  -4.419003E-15
       310      G      3.505192E-31   1.000000E+00   2.659543E-34  -1.878151E-16  -1.034798E-34  -4.517339E-15
       311      G      3.505192E-31   1.000000E+00   7.254929E-36  -1.878151E-16  -1.034798E-34  -4.517339E-15
       312      G      3.505192E-31   1.000000E+00   5.246537E-34  -1.878151E-16  -1.034798E-34  -4.517339E-15

     EIGENVALUE =  0.000000E+00
     CYCLES =  0.000000E+00         R E A L   E I G E N V E C T O R   N O .         2

 POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
        90      G      0.0            2.083331E-09   0.0            6.666667E-02   0.0            0.0
        97      G      0.0            2.083331E-09   0.0            6.666667E-02   0.0            3.231174E-26
        98      G      0.0            2.083331E-09   0.0            6.666667E-02   0.0            8.077936E-28
        99      G      6.381248E-33   2.083331E-09   0.0            6.666667E-02   0.0           -1.068990E-16
       100      G      1.913569E-32   2.083329E-09   0.0            6.666667E-02   0.0           -2.464865E-16
       110      G      1.232810E-15   2.083330E-09   3.333333E-01   6.666667E-02  -2.867730E-18  -2.465620E-16
       111      G      1.232810E-15   2.083330E-09   3.333333E-01   6.666667E-02  -2.867730E-18  -2.465620E-16
       112      G      1.232810E-15   2.083329E-09   3.333333E-01   6.666667E-02  -2.867730E-18  -2.465620E-16
       120      G      3.698430E-15   2.083331E-09   1.000000E+00   6.666667E-02  -6.452392E-18  -2.465620E-16
       121      G      3.698430E-15   2.083332E-09   1.000000E+00   6.666667E-02  -6.452392E-18  -2.465620E-16
       122      G      3.698430E-15   2.083331E-09   1.000000E+00   6.666667E-02  -6.452392E-18  -2.465620E-16
       310      G      1.874572E-32  -3.333333E-01   2.246368E-34   6.666667E-02  -1.179362E-34  -2.487544E-16
       311      G      1.874572E-32  -3.333333E-01  -7.020377E-35   6.666667E-02  -1.179362E-34  -2.487544E-16
       312      G      1.874572E-32  -3.333333E-01   5.194774E-34   6.666667E-02  -1.179362E-34  -2.487544E-16

     EIGENVALUE =  0.000000E+00
     CYCLES =  0.000000E+00         R E A L   E I G E N V E C T O R   N O .         3

 POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
        90      G      0.0           -1.280440E-07   0.0            2.430115E-10   0.0            5.590732E-02
        97      G      0.0           -8.386099E-01   0.0            2.430115E-10   0.0            5.590732E-02
        98      G      0.0           -2.795367E-01   0.0            2.430115E-10   0.0            5.590732E-02
        99      G     -1.446326E-18   2.795365E-01   0.0            2.430114E-10   0.0            5.590732E-02
       100      G     -4.338979E-18   8.386096E-01   0.0            2.430113E-10   0.0            5.590732E-02
       110      G     -2.795366E-01   6.772192E-01   1.215056E-09   2.430113E-10  -1.045336E-26   5.590732E-02
       111      G     -2.795366E-01   5.374509E-01   1.215056E-09   2.430113E-10  -1.045336E-26   5.590732E-02
       112      G     -2.795366E-01   8.169875E-01   1.215056E-09   2.430113E-10  -1.045336E-26   5.590732E-02
       120      G     -8.386098E-01   3.544383E-01   3.645169E-09   2.430113E-10  -2.352006E-26   5.590732E-02
       121      G     -8.386098E-01   2.146700E-01   3.645169E-09   2.430113E-10  -2.352006E-26   5.590732E-02
       122      G     -8.386098E-01   4.942066E-01   3.645169E-09   2.430113E-10  -2.352006E-26   5.590732E-02
       310      G     -4.338979E-18   1.000000E+00  -1.348490E-33   2.430113E-10   7.099896E-34   5.590732E-02
       311      G     -4.338979E-18   8.602317E-01   4.264840E-34   2.430113E-10   7.099896E-34   5.590732E-02
       312      G     -4.338979E-18   1.139768E+00  -3.123464E-33   2.430113E-10   7.099896E-34   5.590732E-02
```

Listing 8-38 Output for Estimation of Dynamic Stability Derivatives (Continued)

```
      MATRIX QHHL     (GINO NAME 101 ) IS A CMP D.P.          6 COLUMN X          3 ROW RECTANG  MATRIX.
COLUMN      1      ROWS      1 THRU      3     --------------------------------------------------
   ROW
     1)  1.2752D-05,-2.8634D-02  -1.4758D-05, 3.4945D-03   1.7980D-05,-2.3189D-02
COLUMN      2      ROWS      1 THRU      3     --------------------------------------------------
   ROW
     1) -2.1631D-05,-4.2480D-03   5.6038D-05,-5.9515D-02  -1.8804D-05,-3.1072D-03
COLUMN      3      ROWS      1 THRU      3     --------------------------------------------------
   ROW
     1) -8.0042D+00,-3.5915D-02   9.7683D-01, 9.2522D-03  -6.4820D+00,-3.2783D-02
COLUMN      4      ROWS      1 THRU      3     --------------------------------------------------
   ROW
     1)  1.2748D-03,-2.8634D-01  -1.4776D-03, 3.4947D-02   1.7977D-03,-2.3189D-01
COLUMN      5      ROWS      1 THRU      3     --------------------------------------------------
   ROW
     1) -2.1650D-03,-4.2464D-02   5.5982D-03,-5.9523D-01  -1.8821D-03,-3.1060D-02
COLUMN      6      ROWS      1 THRU      3     --------------------------------------------------
   ROW
     1) -8.0034D+00,-3.5914D-01   9.7541D-01, 9.2577D-02  -6.4807D+00,-3.2782D-01
THE NUMBER OF NON-ZERO TERMS IN THE DENSEST COLUMN =       3
THE DENSITY OF THIS MATRIX IS 100.00 PERCENT.
```

Servoelastic Stability Analysis of a Missile (Example HA110A)

This example of servoelastic stability analysis uses Solution 110, Modal Complex Eigenvalues, rather than Solution 145 since no aerodynamic forces are included. This example of a typical air-to-air missile has been considered by Anon. (1971) [Reference 3], Rodden and Harder (1975) [Reference 53], and Rodden, Harder, and Bellinger (1979) [Reference 50] but with an incorrect transfer function for one of the servo elements (the actuator). The fuselage/flipper configuration is idealized as a uniform beam with an all-movable aft section. This is an oversimplification of a typical missile since the aft fuselage is never hinged and a very light flipper is usually hinged near its midchord. The missile is assumed to weigh $M + 1000$ lb, to be $L = 150$ in long, and to have a fundamental frequency of $f_1 = 45.0$ Hz.

The present example introduces further significant modifications and provides a suitably representative idealization of an air-to-air missile, and should be regarded as a replacement for the earlier analysis. The missile is modeled as a right-half-model while the flipper is modeled as a light weight (5 lb) plate represented by four CQUAD4 elements, each 0.500 in thick, and with densities adjusted to give a total weight of 5 lbs and a center of gravity 1.0 in forward of the hinge line, which is placed midway between GRIDs 9 and 10. The one-sided structural model and the servo system are discussed below. The structural model is discussed first.

The structural grid points are numbered 1 through 10 as shown in Figure 8-20. A rate gyro, located halfway between GRIDs 4 and 5, is assigned the number 45 with the origin of coordinates placed there. GRID 11 is the flipper hinge line station. GRIDs 1 through 11 and GRID 45 are constrained to be free only in plunge and pitch, that is, only the symmetrical case is being considered. CBAR, PBAR, and MAT1 entries represent the aluminum beam structure (assumed weightless), and the weight of the structure is modeled to be concentrated at the grid points via CONM2 entries. The bending stiffnesses, I_y and I_z, are found from the vibration analysis result of Timoshenko, Young, and Weaver (1974, p. 424 [Reference 59]),

$$\omega_1(M/LEI)^{1/2} = (4.730/L)^2$$

and the desired fundamental frequency, $f_1 = \omega_1/2\pi = 45.0\ \text{Hz}$; the one-side stiffnesses become

$$I_y = I_z = 135.54\ \text{in}^4 .$$

A very large cross-sectional area and polar moment of inertia are selected arbitrarily. The first eight CONM2 entries give the weight of each as 50.0 lb at GRIDs 1 through 8. The weight of the vertical flippers in the cruciform configuration have been included by adding the weight of one flipper divided between GRIDS 9 and 10 according to its center of gravity location, and the weight at GRID 9 becomes 52.833 lbs and at GRID 10 becomes 52.167 lbs.

The flipper is modeled by four equal CQUAD4 elements with corner GRIDs 21 through 29 as shown in Figure 8-20. The flipper is connected to the fuselage at GRID 24, and an RBAR is extended from GRID 11 on the fuselage centerline to GRID 12 at the side of the fuselage coincident with GRID 24. Multipoint constraints connect GRIDs 12 and 24 together except for the pitch degree of freedom. The flipper rotation δ is defined by Scalar Point SPOINT 49 and is the difference between the pitch rotations (R2) of GRIDs 24 and 12; the sign convention for the flipper angle δ is positive with the trailing edge down. The flipper and its hinge are idealized to be very stiff, and this condition is realized by providing lateral constraints (T2) on GRIDs 21 and 27 and by choosing a large modulus of elasticity (1.0E+10) on the MAT1 10 and MAT1 20 Bulk Data entries; the densities of 0.0188889 and 0.0144444 on MAT1 10 and MAT1 20 lead to the desired weight and center of gravity for the flipper. PARAM,GRDPNT,45 generates the inertial data for the fuselage/flipper combination relative to GRID 45. PARAM,WTMASS converts the weights to mass units.

Structural damping is included as an equivalent frequency-dependent viscous damping through the table TABDMP1, assuming that $g_1 = 0.03$ in the first mode, $g_2 = 0.05$ in the second mode, and $g_3 = 0.08$ in the third mode. The vibration analysis gives the first three undamped frequencies as $f_1 = 45.2$, $f_2 = 126.7$ and $f_3 = 251.0\ \text{Hz}$. The damping-frequency pairs provide the data necessary for the tabular damping format.

The structural model including the grid, stiffness, inertial, and damping data is contained in input file struct.dat shown in Listing 8-39.

Next, the servo system is considered. The block diagram shown in Figure 8-21 is an oversimplification of an air-to-air missile control system, but is adequate for illustrative purposes. The signals in Figure 8-21 denoted by e_i generally represent voltages or quantities equivalent to voltages output by the various servo elements. The transfer functions are as follows. For the command error:

$$e_1 = e_c + e_4 \tag{8-54}$$

for the position potentiometer,

$$\frac{e_2}{\delta} = K_p \tag{8-55}$$

for the servo position error,

$$e_3 - e_1 + e_2 = 0 \tag{8-56}$$

for the actuator,

$$\frac{\delta}{e_3} = \frac{K_a}{p(T_a p + 1)} \tag{8-57}$$

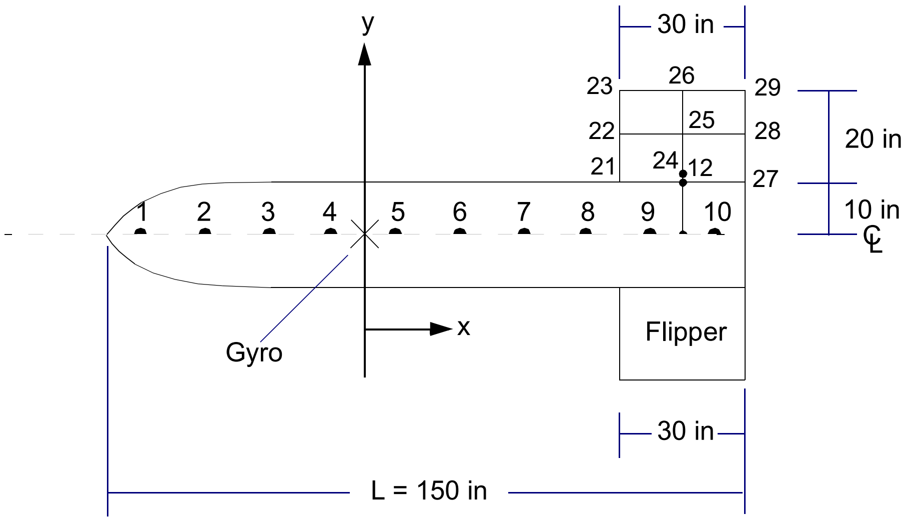

Figure 8-20 Uniform Missile-Flipper Idealization

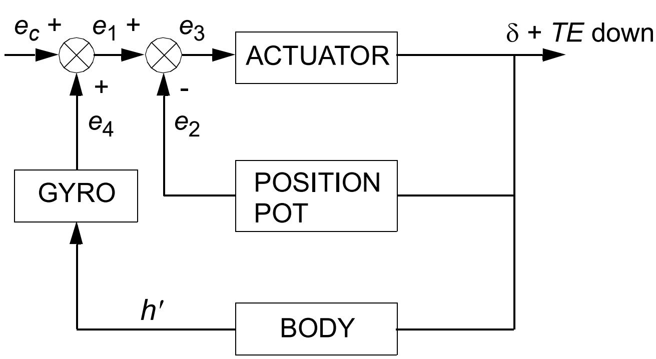

Figure 8-21 Missile Servo Block Diagram

and for the rate gyro,

$$\frac{e_4}{h'} = \frac{K_g p}{(p^2/\omega_g^2 + 2\zeta_g p/\omega_g + 1)} \tag{8-58}$$

in which p denotes the Laplace transform operator. The flipper rotation, δ, is considered as part of the servo system and is assigned extra point numbers EPOINT 50 (it is also SPOINT 49 when considered as part of the flipper structure). The signals e_1, e_2, e_3, and e_4, respectively, are given the extra point numbers 51, 52, 53, and 54. The slope of the beam, $h' = \partial h/\partial x$ at the rate gyro, is the rotation (R2) of GRID 45. The MSC Nastran transfer function TF entry assumes a single output and multiple inputs of the form

$$(B0 + B1p + B2p^2)u_d + \sum_i (A0(i) + A1(i)p + A2(i)p^2)u_i = 0 \tag{8-59}$$

The transfer functions are rewritten in this format as follows:

For EPOINT 50 (δ)

$$(p + T_a p^2)\delta - K_a e_3 = 0 \tag{8-60}$$

for EPOINT 51 (e_1)

$$e_1 - e_4 = 0 \tag{8-61}$$

for EPOINT 52 (e_2)

$$e_2 - K_p\delta = 0 \tag{8-62}$$

for EPOINT 53 (e_3)

$$e_3 - e_1 + e_2 = 0 \tag{8-63}$$

and for EPOINT 54 (e_4)

$$\left(1 + \frac{2\zeta_g p}{\omega_g} + \frac{p^2}{\omega_g^2}\right)e_4 - K_g p h' = 0 \tag{8-64}$$

The numerical values assumed for the servo time constants are $K_a = 50.0\ \text{deg}$ per deg/s, $T_a = 0.002\ \text{s}$, $K_p = 1.0\ \text{deg/deg}$, $\omega_g = 60.0\ \text{Hz} = 376.991\ \text{rad/s}$, $\zeta_g = 0.70$, and $K_g = 0.13\ \text{deg}$ per deg/s.

One additional transfer function is necessary to make the servo representation and the structural representation of the flipper angles the same, that is, SPOINT 49 and EPOINT 50 should be identical. This can be done by introducing a stiff spring between the two that would approximate the actuator stiffness, that is, the oil column stiffness, the cylinder breathing (radial) stiffness, and the piston rod stiffness. If the structural and servo representations of the flipper angles are denoted by δ_{49} and δ_{50}, respectively, then the transfer function can be written as

$$K_f(\delta_{49} - \delta_{50}) = 0 \tag{8-65}$$

where K_f is selected large enough that the new frequency added to the system is above the range of interest and no damping is considered. The value $K_f = 1.0E+8$ adds the frequency $f_f = 1631.7\ \text{Hz}$, which is sufficiently higher than the third fuselage bending frequency of $f_3 = 251.0\ \text{Hz}$. The above equation is written as equaling zero but this is not actually the case. In MSC Nastran the TF terms are added to the existing system of equations and, in this case, the TF terms are added to the flipper hinge-moment equation and give rise to the new frequency because of the stiffness K_f and the moment of inertia of the flipper.

The above six equations are placed on the TF entries, which are contained in input file servo.dat along with the definitions of the SPOINT and EPOINTs and are shown in Listing 8-40.

The use of the additional transfer function above to make SPOINT 49 and EPOINT 50 approximately equal is a realistic approach to the problem since an actuator has only a finite stiffness. However, if it is desired to make SPOINT 49 and EPOINT 50 exactly equal; that is, to assume a rigid actuator, this can be done by the Lagrange Multiplier technique discussed in the *MSC Nastran Dynamic Analysis User's Guide*. This requires the addition of another scalar point, SPOINT 48, which can be interpreted as the actuator hinge moment.

The structural and servo models are called into the Bulk Data Section by means of the INCLUDE entry. The vibration analysis for the three rigid body modes of fuselage plunge and pitch and the open loop flipper rotation along with the three flexible modes is carried out by the modified Householder eigenvalue method as specified on the EIGR entry. All six modes are included in the modal formulation via PARAM,LMODES, and the complex eigenvalues are requested on the EIGC entry by the QZ method (HESS) with the eigenvectors to be normalized on their maximum components. ENDDATA completes the Bulk Data Section.

Input

The input data file for this example is shown in Listing 8-41. The bulk data section of Listing 8-41 INCLUDES the struct.dat and servo.dat files of Listing 8-39 and Listing 8-40, respectively. In addition, it contains specifications of the real and complex eigenanalyses.

The Executive Control Section begins with the identification ID MSC, HA110A. SOL 110 specifies the modal complex eigenvalue solution sequence. The CEND statement completes the Executive Control Section.

The Case Control Section begins with the three title entries. ECHO = BOTH requests both annotated and sorted Bulk Data be printed. MPC = 50 specifies the constraints on the flipper (QUAD4) GRIDs and the flipper rotation in terms of the pitch rotations of GRIDs 24 and 12. SDAMP = 1 specifies the modal damping. TFL = 1 specifies the set number for the transfer functions, the TF entries. METHOD = 14 calls for the modified Householder real eigenvalue (vibration) method on EIGR; SVEC = ALL requests the vibration modes. CMETHOD = 40 calls for the complex Hessenberg (QZ) eigenvalue method on the ElGC entry. SDISP = ALL requests the modal participation factors and the extra point displacements for each eigenvalue. DISP = ALL requests the grid point displacements for each complex eigenvalue. The BEGIN BULK command completes the Case Control Section.

Output

Representative output results are contained in Listing 8-43. The results are discussed below.

The weight analysis is the first output. The half-missile weighs 510.0 lbs and has a center of gravity 16.157 inches aft of the rate gyro location at Station 61.157. The vibration frequencies for the open loop are three computed zeroes and three fuselage frequencies slightly coupled with the overbalanced flipper, $f_1 = 45.17\ \text{Hz}$, $f_2 = 126.74\ \text{Hz}$ and $f_3 = 251.04\ \text{Hz}$.

The rigid body modes and the coupled bending modes are shown next, and the flipper coupling is evident. The 22 roots from the closed-loop servoelastic solution consist of four zero roots from the two rigid body modes, four complex conjugate pairs from the three coupled vibration modes ($f_1 = 45.13\ \text{Hz}$, $g_1 = 0.0254$; $f_2 = 126.12\ \text{Hz}$, $g_2 = 0.0507$; $f_3 = 249.34\ \text{Hz}$, $g_3 = 0.0786$). The frequency is introduced (with no damping) by the flipper servo/structure connection transfer function ($f_f = 1631.7$), two real roots from the actuator/potentiometer loop ($p = -440.29$ corresponding to $T_a = 0.002$ and $p = -56.324$ corresponding to $K_a = 50.0$), a complex conjugate pair from the rate-gyro ($f_g = 42.85\ \text{Hz}$ and $g_g = 1.981$. Note that these are coupled values that correspond closely to the uncoupled input values of $\omega_g = 60.0$ and $\zeta_g = 0.70$), and the six zero roots artificially added to permit the use of HESS by making the mass matrix nonsingular.

Closing the servo loop is seen to cause only slight changes in the open loop root characteristics. The modal displacement output also shows the same lack of coupling. The modal displacements include the amplitudes of the vibration modes and the extra points. The grid point displacement output (note that it is not normalized) shows the servoelastic mode shapes and includes the scalar point SPOINT 49. Note that the amplitudes for EPOINT 50 and SPOINT 49 are equal as expected for the lower modes where there are only small modal convergence errors.

Listing 8-39 struct.dat Input File

```
$*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
$                                                                        $
$                       * * * STRUCTURAL DATA * * *                      $
$                                                                        $
$                            (LB-IN-SEC SYSTEM)                          $
$                                                                        $
$                          * * GRID GEOMETRY * *                         $
$                                                                        $
$        GRID 1 - 10   (T3,R2)  FUSELAGE POINTS                          $
$        GRID 45       (T3,R2)  SERVO SENSOR POINT                       $
$                                                                        $
$                            * FUSELAGE GRID *                           $
$                                                                        $
$        THE GRID ENTRY DEFINES THE LOCATION OF A STRUCTURAL GRID        $
$        POINT.  LISTED ARE ITS COORDINATE SYSTEM ID, ITS LOCATION,      $
$        THE ID OF THE COORDINATE SYSTEM IN WHICH ITS DISPLACEMENTS      $
$        ARE DEFINED, ITS PERMANENT SINGLE-POINT CONSTRAINTS AND         $
$        ITS ASSOCIATED SUPERELEMENT ID.                                 $
$                                                                        $
$       ID      CP      X1      X2      X3      CD      PS      SEID
GRID    1               -52.5   0.      0.              246
GRID    2               -37.5   0.      0.              246
GRID    3               -22.5   0.      0.              246
GRID    4                -7.5   0.      0.              246
GRID    5                 7.5   0.      0.              246
GRID    6                 22.5  0.      0.              246
GRID    7                 37.5  0.      0.              246
GRID    8                 52.5  0.      0.              246
GRID    9                 67.5  0.      0.              246
GRID    10                82.5  0.      0.              246
GRID    45                 0.0  0.      0.              1246
GRID    21                60.0  10.     0.              26
GRID    22                60.0  20.     0.              6
GRID    23                60.0  30.     0.              6
GRID    24                75.0  10.     0.              6
GRID    25                75.0  20.     0.              6
GRID    26                75.0  30.     0.              6
GRID    27                90.0  10.     0.              26
GRID    28                90.0  20.     0.              6
GRID    29                90.0  30.     0.              6
GRID    11                75.0  0.      0.              246
GRID    12                75.0  10.     0.
$
$       SID     G       C       A       G       C       A
MPC     50      24      1       1.0     12      1       -1.0
MPC     50      24      2       1.0     12      2       -1.0
MPC     50      24      3       1.0     12      3       -1.0
MPC     50      24      4       1.0     12      4       -1.0
$
MPC     50      49              1.0     24      5       -1.0            +MPC50
+MPC50          12      5       1.0
$
$             * * STRUCTURAL STIFFNESS PROPERTIES * *                    $
$                                                                        $
$                       * FUSELAGE STRUCTURE *                           $
$                                                                        $
$        THE CBAR ENTRY DEFINES A SIMPLE BEAM ELEMENT.  LISTED ARE       $
$        ITS PROPERTY ENTRY ID, THE TWO GRID POINTS JOINED BY THE        $
$        BEAM AND COMPONENTS OF A VECTOR FROM THE FIRST POINT.           $
$        THIS VECTOR DEFINES THE DIRECTION OF THE STRUCTURAL DE-         $
$        FLECTION OF THE POINT AND ITS POSITIVE SENSE.                   $
$                                                                        $
$       EID     PID     GA      GB      X1,GO   X2      X3
CBAR     1      1        1       2      0.0     0.0     1.0
CBAR     2      1        2       3      0.0     0.0     1.0
CBAR     3      1        3       4      0.0     0.0     1.0
CBAR     4      1        4      45      0.0     0.0     1.0
CBAR    45      1       45       5      0.0     0.0     1.0
CBAR     5      1        5       6      0.0     0.0     1.0
CBAR     6      1        6       7      0.0     0.0     1.0
CBAR     7      1        7       8      0.0     0.0     1.0
CBAR     8      1        8       9      0.0     0.0     1.0
CBAR     9      1        9      11      0.0     0.0     1.0
CBAR    10      1       11      10      0.0     0.0     1.0
$                                                                        $
THE PBAR ENTRY DEFINES GEOMETRIC PROPERTIES OF THE BEAM.       $
$        LISTED ARE ITS ASSOCIATED MATERIAL ENTRY ID, ITS CROSS SEC-     $
$        TIONAL AREA, AREA MOMENTS OF INERTIA, TORSIONAL MOMENT          $
$        OF INERTIA AND NON-STRUCTURAL MASS PER UNIT AREA.  THE          $
$        OPTIONAL CONTINUATION ENTRY CONTAINS STRESS RECOVERY            $
$        COEFFICIENTS, that is, Y,Z COORDINATES WHERE STRESSES ARE          $
$        TO BE COMPUTED.  K1 AND K2 ARE AREA FACTORS FOR SHEAR           $
$        CALCULATIONS AND I12 IS THE AREA CROSS PRODUCT OF INERTIA.      $
$                                                                        $
$       PID     MID     A       I1      I2      J       NSM
PBAR    1       1       1.0+8   67.77   67.77   1.0+8
```

Listing 8-39   struct.dat Input File (Continued)

```
$                       * * PHYSICAL PROPERTIES * *                     $
$                                                                       $
$        THE MAT1 ENTRY DEFINES THE MATERIAL PROPERTIES.  LISTED        $
$        ARE ITS ID, ITS ELASTIC MODULUS, SHEAR MODULUS, POISSONS       $
$        RATIO, MASS DENSITY, TEMPERATURE EXPANSION COEFFICIENT,        $
$        REFERENCE TEMPERATURE AND A STRUCTURAL DAMPING COEFFICIENT.    $
$                                                                       $
$       MID     E       G       NU      RHO     A       TREF    GE
MAT1    1       10.3+6          0.33    0.0
$
$
$                    * * MASS AND INERTIA PROPERTIES * *                $
$                                                                       $
$                           * FUSELAGE MASSES *                         $
$                                                                       $
$        THE CONM2 ENTRY DEFINES A CONCENTRATED MASS.  LISTED ARE       $
$        ITS ID, GRID LOCATION, COORDINATE SYSTEM TO LOCATE THE         $
$        CENTER OF GRAVITY, THE MASS VALUE AND THE LOCATION OF          $
$        THE CENTER OF GRAVITY RELATIVE TO THE GRID LOCATION.           $
$                                                                       $
$       EID     G       CID     M       X1      X2      X3
CONM2   1       1               50.
CONM2   2       2               50.
CONM2   3       3               50.
CONM2   4       4               50.
CONM2   5       5               50.
CONM2   6       6               50.
CONM2   7       7               50.
CONM2   8       8               50.
CONM2   9       9               52.833
CONM2   10      10              52.167
$                                                                       $
$                 * * FUSELAGE DAMPING CHARACTERISTICS * *              $
$                                                                       $
$        THE TABDMP1 ENTRY DEFINES MODAL DAMPING AS A TABULAR           $
$        FUNCTION OF FREQUENCY.  THE DAMPING LEVELS ARE LINEAR          $
$        BETWEEN THE FREQUENCY AND DAMPING PAIRS AND EXTRAPOLATED       $
$        OUTSIDE THE TABULATED FREQUENCY RANGE.  THERE IS NO            $
$        PARAMETER, KDAMP,N; THUS KDAMP DEFAULTS TO 1.  THIS            $
$        SPECIFIES THAT THE DAMPING CONSTANTS ARE TO BE A PART          $
$        OF THE DAMPING MATRIX RATHER THAN THE STIFFNESS MATRIX         $
$        AS IS REQUIRED IN THE PK-FLUTTER METHOD.                       $
$                                                                       $
$       ID      TYPE
TABDMP1 1       G                                                        +DMP1
$       F1      G1      F2      G2      ETC             ENDT
+DMP1   0.0     0.03    45.2    0.03    126.7   0.05    251.0   0.08    +DMP2
+DMP2   1000.0  0.08    ENDT
$                                                                       $
$                                                                       $
$                         * * FLIPPER STRUCTURE * *
$
CQUAD4  1       1       21      22      25      24
CQUAD4  2       1       22      23      26      25
CQUAD4  3       2       24      25      28      27
CQUAD4  4       2       25      26      29      28
$
$
$ PROPERTY AND MATERIAL BULK DATA ENTRIES
$
PSHELL  1       10      .500    10
PSHELL  2       20      .500    20
$
MAT1    10      1.0+10          0.30    .0188889
MAT1    20      1.0+10          0.30    .0144444
$
$        THE RBAR ENTRY DEFINES A RIGID BAR.  LISTED ARE THE GRID       $
$        POINTS AT EACH END AND THE DEPENDENT AND INDEPENDENT DOFS      $
$        AT EACH END.  THE NUMBER OF INDEPENDENT DOFS AT THE TWO        $
$        ENDS MUST EQUAL SIX.  BY DEFAULT THOSE NOT DECLARED INDE-      $
$        PENDENT ARE MADE DEPENDENT.                                    $
$                                                                       $
$       EID     GA      GB      CNA     CNB     CMA     CMB
RBAR    11      11      12      123456
$
PARAM   GRDPNT  45
$
$        THE PARAM,WTMASS,GINV CAUSES ALL THE STRUCTURAL MASSES AND     $
$        MASS DENSITIES TO BE MULTIPLIED BY GINV (that is, BY ONE OVER     $
$        THE ACCELERATION OF GRAVITY).                                  $
$                                                                       $
PARAM   WTMASS  .0025907
$
PARAM   COUPMASS1
$
```

Listing 8-40 servo.dat Input File

```
$ DEC/CMS REPLACEMENT HISTORY, Element SERVO.DAT
$ *1     5-JUL-1994 17:12:53 A_BOYADJIAN "68 PLUS/G/ NEW FOR V68 AERO_SS BOOK"
$ DEC/CMS REPLACEMENT HISTORY, Element SERVO.DAT
$                                                                        $
$         * * SERVO SYSTEM EXTRA POINTS AND TRANSFER FUNCTIONS * *       $
$                                                                        $
$                     * SCALAR AND EXTRA POINTS *                        $
$                                                                        $
$       THE SPOINT ENTRY DEFINES SCALAR POINTS OF THE CONTROL            $
$       SYSTEM.                                                          $
$
SPOINT  49
$
$       THE EPOINT ENTRY DEFINES EXTRA POINTS OF THE SERVO               $
$       MODEL.                                                           $
$                                                                        $
$       ID      ID      ID      ID      ETC
EPOINT  50      51      52      53      54
$                                                                        $
$                         * TRANSFER FUNCTIONS *                         $
$                                                                        $
$        THE TF ENTRY DEFINES A SECOND ORDER TRANSFER FUNCTION           $
$        FOR THE GRID OR EXTRA POINT GD IN THE DOF COMPONENT CD          $
$        (CD IS ZERO FOR EXTRA POINTS).  IT LISTS GD, CD AND THE         $
$        COEFFICIENTS B OF THE POLYNOMIAL IN THE LAPLACE TRANSFORM       $
$        VARIABLE P THAT RELATES THE DISPLACEMENTS UD TO OTHER           $
$        DISPLACEMENTS UI, AND IT LISTS THE CORRESPONDING GS,CS AND      $
$        COEFFICIENTS AI FOR THE OTHER DISPLACEMENTS.                    $
$
$
$  SCALAR/EXTRA POINT SPRING (DELETED WHEN LAGRANGE MULTIPLIER IS USED)
$                                                                        $
$       SID     GD      CD      B0      B1      B2
TF      1       49              1.0+8                                   +4950
$       G(1)    C(1)    A0(1)   A1(1)   A2(1)   ETC
+4950   50              -1.0+8
$
$                                   ACTUATOR                             $
$
$        NOTE:  THIS IS NOT THE TRANSFER FUNCTION USED FOR THE           $
$        ACTUATOR IN THE EXAMPLE OF NASA CR 3094, BUT HAS BEEN           $
$        CORRECTED EXTENSIVELY, EVEN BEYOND THE ONE DISCUSSED IN
$        THE FOOTNOTE ON P. 82 OF THAT REPORT,
$                                                                        $
TF      1       50                      1.0     0.002                   +5053
+5053   53              -50.0
$                                                                        $
$                                 COMMAND ERROR                          $
$                                                                        $
$       SID     GD      CD      B0      B1      B2
TF      1       51              1.0
$       G(1)    C(1)    A0(1)   A1(1)   A2(1)   ETC
        54              -1.0
$                                                                        $
$                            POSITION POTENTIOMETER                      $
$                                                                        $
TF      1       52              1.0
        50               -1.0
$                                                                        $
$                              SERVOPOSITION ERROR                       $
$       SID     GD      CD      B0      B1      B2
TF      1       53              1.0
        51              -1.0
        52               1.0
$                                                                        $
$                                   RATE GYRO                            $
$                                                                        $
TF      1       54              1.0     3.7136-37.0362-6                +5445
+5445   45      5               -0.13
$
```

Listing 8-41 Input Files for Servoelastic Stability Analysis of a Missile.

```
 $$$$$$$$           AEROELASTIC ANALYSIS EXAMPLE HA110A         $$$$$$$$
$                                                                      $
$       MODEL DESCRIPTION         TYPICAL AIR-TO-AIR MISSILE -         $
$                                 BAR MODEL WITH 10 FUSELAGE STATIONS  $
$                                 AND AN ACTIVE CONTROLS SYSTEM.       $
$                                                                      $
$       SOLUTION                  MODAL COMPLEX EIGENVALUE SOLUTION    $
$                                 FOR SERVOELASTIC STABILITY ANALYSIS  $
$                                                                      $
$       OUTPUT                    EIGENVALUES AND EIGENVECTORS FOR     $
$                                 USE IN EVALUATING STABILITY          $
$                                                                      $
$$$$$$$$                                                        $$$$$$$$
TIME   5 $ TIME IN CPU MINUTES
SOL 110  $ MODAL COMPLEX EIGENVALUES
CEND
TITLE = EXAMPLE HA110A: FLEXIBLE MISSILE WITH CONTROL SYSTEM   HA110A
SUBTI = SYMMETRIC MOTIONS, NO AERODYNAMIC FORCES
LABEL = HALF-SPAN MODEL, SERVOELASTIC ANALYSIS
  ECHO    = BOTH
  MPC     = 50
  SDAMP   = 1         $ MODAL DAMPING
  TFL     = 1         $ SERVO TRANSFER FUNCTION
$ K2PP    = STIFF     $ DMIG LAGRANGE MULTIPLIER (FOR RIGID ACTUATOR)
  METHOD  = 14        $ MODIFIED HOUSEHOLDER REAL EIGENVALUE METHOD
  SVEC    = ALL       $ VIBRATION MODES
  CMETHOD = 40        $ HESSENBERG COMPLEX EIGENVALUE METHOD
  SDISP   = ALL       $ MODAL PARTICIPATION AND EPOINT AMPLITUDES
  DISP    = ALL       $ GRID DISPLACEMENTS
BEGIN BULK
$*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
$                                                                       $
$       THE ANNOTATIONS IN THIS INPUT DECK ARE INTENDED TO              $
$       EXPLAIN THE DATA ON THE CARD IMAGES FOR THIS SPECIFIC           $
$       EXAMPLE WITHOUT REFERENCE TO THE VARIOUS MANUALS WHERE          $
$       MORE GENERAL DEFINITIONS WILL BE FOUND.                         $
$                                                                       $
INCLUDE 'struct.dat'
$
INCLUDE 'servo.dat'
$
$       SID     METHOD  F1      F2      NE      ND                      +EIG
EIGR    14      MHOU                            6                       +HOU
$+EIG   NORM    G       C
+HOU    MAX
$                                                                       $
$                   * * * SOLUTION SPECIFICATIONS * * *                 $
$                                                                       $
$        THE PARAM,LMODES,N ENTRY SPECIFIES THAT N MODES ARE TO BE      $
$        USED IN THE ANALYSIS.                                          $
$                                                                       $
PARAM   LMODES  6
$                                                                       $
$                 * * SERVOELASTIC STABILITY ANALYSIS * *               $
$                                                                       $
$        THE EIGC ENTRY DEFINES DATA NEEDED TO PERFORM A COMPLEX        $
$        EIGENVALUE ANALYSIS.  THIS ONE SPECIFIES THAT THE UPPER        $
$        HESSENBERG METHOD BE USED TO EXTRACT COMPLEX EIGENVALUES       $
$        AND THAT THE EIGENVECTORS BE NORMALIZED ON THEIR MAXIMUM       $
$        COMPONENTS.  THE CONVERGENCE CRITERION DEFAULTS TO:            $
$                    1.0-4  INVERSE POWER METHOD,                       $
$                    1.0-11 DETERMINANT METHOD,                         $
$                    1.0-15 HESSENBERG METHOD.                          $
$        WHEN THE HESSENBERG METHOD IS SPECIFIED ALL ENTRIES ON THE     $
$        CONTINUATION ENTRY EXCEPT THE NUMBER OF DESIRED ROOTS (NDL)    $
$        ARE IGNORED.                                                   $
$                                                                       $
$       SID     METHOD  NORM    G       C       E
EIGC    40      HESS    MAX                                             +EC
$       ALFA1   OMEGA1  ALFB1   OMEGB1  L1      NE1     ND1
+EC                                                     22
$
ENDDATA
```

Listing 8-42 Output for Servoelastic Stability Analysis of a Missile

```
0                                                    REFERENCE POINT =       45
                                                                 M O
                        *  5.100000E+02  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00 -9.999990E+01 *
                        *  0.000000E+00  5.100000E+02  0.000000E+00  0.000000E+00  0.000000E+00  8.240005E+03 *
                        *  0.000000E+00  0.000000E+00  5.100000E+02  9.999990E+01 -8.240005E+03  0.000000E+00 *
                        *  0.000000E+00  0.000000E+00  9.999990E+01  2.166664E+03 -7.399991E+03  0.000000E+00 *
                        *  0.000000E+00  0.000000E+00 -8.240005E+03 -7.399991E+03  1.096032E+06  0.000000E+00 *
                        * -9.999990E+01  8.240005E+03  0.000000E+00  0.000000E+00  0.000000E+00  1.098199E+06 *
                                                                  S
                                          *  1.000000E+00  0.000000E+00  0.000000E+00 *
                                          *  0.000000E+00  1.000000E+00  0.000000E+00 *
                                          *  0.000000E+00  0.000000E+00  1.000000E+00 *
                               DIRECTION
                          MASS AXIS SYSTEM (S)      MASS              X-C.G.        Y-C.G.        Z-C.G.
                                      X           5.100000E+02      0.000000E+00  1.960782E-01  0.000000E+00
                                      Y           5.100000E+02      1.615687E+01  0.000000E+00  0.000000E+00
                                      Z           5.100000E+02      1.615687E+01  1.960782E-01  0.000000E+00
                                                                 I(S)
                                          *  2.147057E+03  5.784306E+03  0.000000E+00 *
                                          *  5.784306E+03  9.628993E+05  0.000000E+00 *
                                          *  0.000000E+00  0.000000E+00  9.650463E+05 *
                                                                 I(Q)
                                          *  9.629341E+05                             *
                                          *                2.112233E+03               *
                                          *                              9.650463E+05 *
                                                                  Q
                                          *  6.020274E-03  9.999819E-01  0.000000E+00 *
                                          * -9.999819E-01  6.020274E-03  0.000000E+00 *
                                          *  0.000000E+00  0.000000E+00  1.000000E+00 *


                                             R E A L   E I G E N V A L U E S
                                         (AFTER AUGMENTATION OF RESIDUAL VECTORS)
   MODE    EXTRACTION      EIGENVALUE            RADIANS             CYCLES            GENERALIZED         GENERALIZED
    NO.       ORDER                                                                       MASS              STIFFNESS
        1         1        1.261360E-07        3.551563E-04        5.652488E-05        1.632621E-01        2.059323E-08
        2         2        3.550667E-09        5.958748E-05        9.483641E-06        4.326820E-01        1.536310E-09
        3         3        4.399742E-06        2.097556E-03        3.338365E-04        4.296136E-03        1.890189E-08
        4         4        8.055727E+04        2.838261E+02        4.517233E+01        5.257575E-01        4.235359E+04
        5         5        6.341576E+05        7.963401E+02        1.267415E+02        7.764813E-01        4.924115E+05
        6         6        2.487909E+06        1.577311E+03        2.510368E+02        7.707402E-01        1.917532E+06
        7         7        5.975735E+07        7.730288E+03        1.230314E+03        1.000000E+00        5.975735E+07
        8         8        3.822364E+09        6.182527E+04        9.839797E+03        1.000000E+00        3.822364E+09
        9         9        2.576075E+10        1.605016E+05        2.554462E+04        1.000000E+00        2.576075E+10
       10        10        1.395722E+12        1.181407E+06        1.880267E+05        1.000000E+00        1.395722E+12

      EIGENVALUE =  1.261360E-07
          CYCLES =  5.652488E-05         R E A L   E I G E N V E C T O R   N O .          1

      POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
             1      G      0.0                          -2.337822E-01                 -6.469554E-03
             2      G      0.0                          -1.367388E-01                 -6.469554E-03
             3      G      0.0                          -3.969553E-02                 -6.469554E-03
             4      G      0.0                           5.734778E-02                 -6.469554E-03
             5      G      9.013475E-20                  1.543911E-01                 -6.469554E-03
             6      G      2.704038E-19                  2.514344E-01                 -6.469554E-03
             7      G      4.506729E-19                  3.484777E-01                 -6.469554E-03
             8      G      6.309432E-19                  4.455210E-01                 -6.469554E-03
             9      G      8.112122E-19                  5.425644E-01                 -6.469554E-03
            10      G      9.013451E-19                  6.396077E-01                 -6.469554E-03
            11      G      9.013439E-19                  5.910860E-01                 -6.469554E-03
            21      G      1.286364E-18                  1.821720E-01   2.780762E-15  -2.726093E-02
            22      G      1.304358E-18   1.787524E-19   1.821720E-01   1.477225E-15  -2.726093E-02
            23      G      1.484198E-18   1.737500E-19   1.821720E-01   1.772020E-15  -2.726093E-02
            24      G                                                                 -2.726093E-02
            25      G      1.386232E-18   6.374027E-20   5.910860E-01   2.500604E-15  -2.726093E-02
            26      G      1.579365E-18   1.064775E-19   5.910860E-01   1.911665E-15  -2.726093E-02
            27      G      1.337907E-18                  1.000000E+00   2.511880E-15  -2.726093E-02
            28      G      1.412407E-18  -3.514799E-19   1.000000E+00   1.589007E-15  -2.726093E-02
            29      G      1.921654E-18  -4.447983E-19   1.000000E+00   2.220446E-15  -2.726093E-02
            45      G                                    1.058694E-01                 -6.469554E-03
      EIGENVALUE =  3.550667E-09
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CYCLES =   9.483641E-06         R E A L   E I G E N V E C T O R   N O .          2

     POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
            1      G      0.0                          1.000000E+00                 7.891460E-03
            2      G      0.0                          8.816281E-01                 7.891460E-03
            3      G      0.0                          7.632562E-01                 7.891460E-03
            4      G      0.0                          6.448843E-01                 7.891460E-03
            5      G     -5.771361E-20                 5.265124E-01                 7.891460E-03
            6      G     -1.731410E-19                 4.081405E-01                 7.891460E-03
            7      G     -2.885685E-19                 2.897686E-01                 7.891460E-03
            8      G     -4.039968E-19                 1.713967E-01                 7.891460E-03
            9      G     -5.194254E-19                 5.302480E-02                 7.891460E-03
           10      G     -5.771413E-19                -6.534710E-02                 7.891460E-03
           11      G     -5.771408E-19                -6.161150E-03                 7.891460E-03
           21      G     -8.760725E-19                -1.819141E-03  -2.894820E-17  2.894673E-04
           22      G     -8.470255E-19  -1.084878E-19 -1.819141E-03  -1.348773E-17  2.894673E-04
           23      G     -9.532913E-19   1.380851E-19 -1.819141E-03  -1.451476E-17  2.894673E-04
           24      G                                                                2.894673E-04
           25      G     -1.062158E-18   1.140555E-19 -6.161150E-03  -2.419804E-17  2.894673E-04
           26      G     -7.362119E-19  -3.286818E-19 -6.161150E-03  -1.684579E-17  2.894673E-04
           27      G     -8.733467E-19                -1.050316E-02  -2.331035E-17  2.894673E-04
           28      G     -6.196494E-19  -1.152157E-19 -1.050316E-02  -1.290201E-17  2.894673E-04
           29      G     -7.470212E-19  -1.980041E-19 -1.050316E-02  -1.864828E-17  2.894673E-04
           45      G                                   5.856983E-01                 7.891460E-03
     EIGENVALUE =  4.399742E-06
         CYCLES =  3.338365E-04         R E A L   E I G E N V E C T O R   N O .          3

            1      G      0.0                         -1.825812E-03                -4.991344E-05
            2      G      0.0                         -1.077110E-03                -4.991344E-05
            3      G      0.0                         -3.284086E-04                -4.991344E-05
            4      G      0.0                          4.202930E-04                -4.991344E-05
            5      G      2.619481E-21                 1.168994E-03                -4.991344E-05
            6      G      7.858429E-21                 1.917696E-03                -4.991344E-05
            7      G      1.309737E-20                 2.666398E-03                -4.991344E-05
            8      G      1.833635E-20                 3.415099E-03                -4.991344E-05
            9      G      2.357529E-20                 4.163801E-03                -4.991344E-05
           10      G      2.619472E-20                 4.912502E-03                -4.991344E-05
           11      G      2.619469E-20                 4.538151E-03                -4.991344E-05
           21      G      3.761372E-20                 1.000000E+00  -1.833603E-15  6.636412E-02
           22      G      3.802618E-20   5.195159E-21  1.000000E+00  -1.464920E-15  6.636412E-02
           23      G      4.332793E-20   5.054468E-21  1.000000E+00  -2.039167E-15  6.636412E-02
           24      G                                                                6.636412E-02
           25      G      4.055916E-20   1.918645E-21  4.538151E-03  -1.942890E-15  6.636412E-02
           26      G      4.600146E-20   3.122172E-21  4.538151E-03  -1.589007E-15  6.636412E-02
           27      G      3.874440E-20                -9.909237E-01  -1.700029E-15  6.636412E-02
           28      G      4.077935E-20  -1.008783E-20 -9.909237E-01  -1.068590E-15  6.636412E-02
           29      G      5.707680E-20  -1.295084E-20 -9.909237E-01  -1.609823E-15  6.636412E-02
           45      G                                   7.946437E-04                -4.991344E-05
     EIGENVALUE =  8.055727E+04
         CYCLES =  4.517233E+01         R E A L   E I G E N V E C T O R   N O .          4

     POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
            1      G      0.0                          1.000000E+00                 3.957338E-02
            2      G      0.0                          4.148083E-01                 3.789159E-02
            3      G      0.0                         -1.164419E-01                 3.214863E-02
            4      G      0.0                         -5.268358E-01                 2.184270E-02
            5      G      9.534943E-20                -7.543173E-01                 8.055652E-03
            6      G      2.860477E-19                -7.618729E-01                -7.057891E-03
            7      G      4.767434E-19                -5.486976E-01                -2.094803E-02
            8      G      6.674403E-19                -1.505695E-01                -3.141066E-02
            9      G      8.581318E-19                 3.706048E-01                -3.726979E-02
           10      G      9.534789E-19                 9.466013E-01                -3.895796E-02
           11      G      9.534783E-19                 6.554547E-01                -3.854272E-02
           21      G      1.428186E-18                 5.243272E-01   3.241577E-05 -8.743307E-03
           22      G      1.347365E-18   1.300965E-19  5.245981E-01   1.985664E-05 -8.732798E-03
           23      G      1.550126E-18   1.480092E-19  5.248501E-01   2.969630E-05 -8.741509E-03
           24      G                                                               -8.743030E-03
           25      G      1.533107E-18   1.089846E-19  6.556454E-01   3.514602E-05 -8.743030E-03
           26      G      1.553073E-18   7.483244E-20  6.559645E-01   2.787199E-05 -8.743030E-03
           27      G      1.325735E-18                 7.866181E-01   3.241549E-05 -8.742753E-03
           28      G      1.328370E-18  -1.299167E-19  7.868890E-01   1.985636E-05 -8.753262E-03
           29      G      2.284375E-18  -2.849001E-20  7.871410E-01   2.969602E-05 -8.744550E-03
           45      G                                  -6.664272E-01                 1.527356E-02
     EIGENVALUE =  6.341576E+05
         CYCLES =  1.267415E+02         R E A L   E I G E N V E C T O R   N O .          5

     POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
            1      G      0.0                          1.000000E+00                 8.089691E-02
            2      G      0.0                         -1.472577E-01                 6.765770E-02
            3      G      0.0                         -9.070868E-01                 2.988964E-02
            4      G      0.0                         -9.910961E-01                -1.844858E-02
            5      G     -6.420669E-20                -4.264310E-01                -5.222651E-02
            6      G     -1.926199E-19                 4.090629E-01                -5.267721E-02
            7      G     -3.210258E-19                 9.860994E-01                -1.957074E-02
            8      G     -4.494148E-19                 9.207536E-01                 2.862205E-02
            9      G     -5.777967E-19                 1.782326E-01                 6.665592E-02
           10      G     -6.420024E-19                -9.550101E-01                 7.996654E-02
           11      G     -6.419931E-19                -3.635057E-01                 7.666866E-02
           21      G     -1.104257E-18                -2.906503E-01  -1.420747E-04  4.863505E-03
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          22      G     -1.314616E-18  -3.781737E-19  -2.918381E-01  -8.705867E-05   4.817413E-03
          23      G     -1.548414E-18  -3.369817E-19  -2.929428E-01  -1.301749E-04   4.855561E-03
          24      G                                                                  4.862216E-03
          25      G     -1.242791E-18  -4.312186E-20  -3.643414E-01  -1.540204E-04   4.862213E-03
          26      G     -1.893786E-18  -2.418679E-19  -3.657398E-01  -1.221748E-04   4.862210E-03
          27      G     -1.034224E-18                 -4.365168E-01  -1.420651E-04   4.860927E-03
          28      G     -1.195170E-18   1.064436E-18  -4.377044E-01  -8.704894E-05   4.907013E-03
          29      G     -3.027953E-18   2.352505E-18  -4.388091E-01  -1.301651E-04   4.868858E-03
          45      G                                 -7.720972E-01                 -3.879774E-02
    EIGENVALUE =  2.487909E+06
        CYCLES =  2.510368E+02         R E A L   E I G E N V E C T O R   N O .         6

    POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
           1      G      0.0                           -8.031675E-01                 -1.101790E-01
           2      G      0.0                            6.409355E-01                 -6.846268E-02
           3      G      0.0                            1.000000E+00                  2.339617E-02
           4      G      0.0                            1.144860E-01                  8.016788E-02
           5      G      2.757453E-19                  -9.401705E-01                  4.396639E-02
           6      G      8.272291E-19                  -9.540685E-01                 -4.232252E-02
           7      G      1.378708E-18                   8.801113E-02                 -8.031262E-02
           8      G      1.930110E-18                   9.889024E-01                 -2.502116E-02
           9      G      2.481548E-18                   6.519109E-01                  6.761730E-02
          10      G      2.757272E-18                  -7.906069E-01                  1.104467E-01
          11      G      2.757222E-18                   1.096597E-02                  9.973578E-02
          21      G      1.179144E-18                   8.754114E-03   1.703824E-05  -1.482460E-04
          22      G      9.682269E-19  -7.453478E-19   8.896596E-03   1.045220E-05  -1.427056E-04
          23      G      1.549437E-18  -3.192142E-19   9.029188E-03   1.561893E-05  -1.472676E-04
          24      G                                                               -1.480616E-04
          25      G      1.355253E-18  -1.140731E-18   1.106613E-02   1.846251E-05  -1.480601E-04
          26      G      4.182395E-19  -2.395570E-18   1.123382E-02   1.465776E-05  -1.480585E-04
          27      G      3.041050E-18                   1.319596E-02   1.703371E-05  -1.478772E-04
          28      G      5.405328E-18   3.135799E-18   1.333840E-02   1.044762E-05  -1.534145E-04
          29      G     -8.426607E-18   8.014895E-18   1.347094E-02   1.561431E-05  -1.488495E-04
          45      G                                 -4.807200E-01                  7.443208E-02
 *** USER INFORMATION MESSAGE 7588 (GKAM)
     BASED ON THE USER PARAMETERS LMODES, LFREQ OR HFREQ, ONLY        6 OF THE       10 COMPUTED STRUCTURE MODES
     (MODES        1 THROUGH        6) WILL BE USED IN THIS MODAL COMPLEX EIGENVALUE ANALYSIS
     (DETAILS OF THE EIGENVALUE DATA FOR THE MODES USED ARE GIVEN BELOW)
1    EXAMPLE HA110A: FLEXIBLE MISSILE WITH CONTROL SYSTEM   HA110A          APRIL  11, 2019  MSC Nastran  4/11/19   PAGE    34
      SYMMETRIC MOTIONS, NO AERODYNAMIC FORCES
0     HALF-SPAN MODEL, SERVOELASTIC ANALYSIS

                                                  R E A L   E I G E N V A L U E S
                                            (ACTUAL MODES USED IN THE DYNAMIC ANALYSIS)
   MODE    EXTRACTION      EIGENVALUE            RADIANS             CYCLES            GENERALIZED         GENERALIZED
    NO.       ORDER                                                                       MASS              STIFFNESS
        1         1        1.261360E-07        3.551563E-04        5.652488E-05        1.632621E-01        2.059323E-08
        2         2        3.550667E-09        5.958748E-05        9.483641E-06        4.326820E-01        1.536310E-09
        3         3        4.399742E-06        2.097556E-03        3.338365E-04        4.296136E-03        1.890189E-08
        4         4        8.055727E+04        2.838261E+02        4.517233E+01        5.257575E-01        4.235359E+04
        5         5        6.341576E+05        7.963401E+02        1.267415E+02        7.764813E-01        4.924115E+05
        6         6        2.487909E+06        1.577311E+03        2.510368E+02        7.707402E-01        1.917532E+06

                                             C O M P L E X   E I G E N V A L U E   S U M M A R Y
0                ROOT     EXTRACTION                  EIGENVALUE                     FREQUENCY              DAMPING
                  NO.        ORDER             (REAL)           (IMAG)                (CYCLES)            COEFFICIENT
                     1           1        -8.987314E-07    -6.378962E-05         1.015243E-05          2.817798E-02
                     2           2        -8.987314E-07     6.378962E-05         1.015243E-05          2.817798E-02
                     3           3        -5.393418E-06    -3.696291E-04         5.882829E-05          2.918287E-02
                     4           4        -5.393418E-06     3.696291E-04         5.882829E-05          2.918287E-02
                     5           5        -5.632386E+01     0.0                  0.0                   0.0
                     6           6        -3.600681E+00    -2.835854E+02         4.513402E+01          2.539398E-02
                     7           7        -3.600681E+00     2.835854E+02         4.513402E+01          2.539398E-02
                     8           8        -2.666099E+02    -2.692103E+02         4.284615E+01          1.980682E+00
                     9           9        -2.666099E+02     2.692103E+02         4.284615E+01          1.980682E+00
                    10          10        -4.402915E+02     0.0                  0.0                   0.0
                    11          11        -2.010827E+01    -7.924460E+02         1.261217E+02          5.074988E-02
                    12          12        -2.010827E+01     7.924460E+02         1.261217E+02          5.074988E-02
                    13          13        -6.156797E+01    -1.566627E+03         2.493364E+02          7.859939E-02
                    14          14        -6.156797E+01     1.566627E+03         2.493364E+02          7.859939E-02
                    15          15        -9.602523E-01    -1.025234E+04         1.631710E+03          1.873236E-04
                    16          16        -9.602523E-01     1.025234E+04         1.631710E+03          1.873236E-04

   COMPLEX EIGENVALUE = -5.632386E+01,  0.000000E+00
                                        C O M P L E X   E I G E N V E C T O R   NO.          5
                                                          (REAL/IMAGINARY)

    POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
0          1      G      0.0            0.0           -9.180267E-04   0.0           -1.295484E-06   0.0
                         0.0            0.0            0.0            0.0            0.0            0.0
0          2      G      0.0            0.0           -8.971644E-04   0.0           -1.581478E-06   0.0
                         0.0            0.0            0.0            0.0            0.0            0.0
0          3      G      0.0            0.0           -8.687258E-04   0.0           -2.238769E-06   0.0
                         0.0            0.0            0.0            0.0            0.0            0.0
0          4      G      0.0            0.0           -8.302713E-04   0.0           -2.842069E-06   0.0
                         0.0            0.0            0.0            0.0            0.0            0.0
0          5      G      1.954842E-21   0.0           -7.838335E-04   0.0           -3.371410E-06   0.0
                         0.0            0.0            0.0            0.0            0.0            0.0
0          6      G      5.864516E-21   0.0           -7.259043E-04   0.0           -4.545695E-06   0.0
                         0.0            0.0            0.0            0.0            0.0            0.0
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0         7      G      9.774187E-21   0.0            -6.407181E-04  0.0            -7.068894E-06  0.0
                        0.0            0.0             0.0           0.0             0.0           0.0
0         8      G      1.368388E-20   0.0            -5.089843E-04  0.0            -1.056273E-05  0.0
                        0.0            0.0             0.0           0.0             0.0           0.0
0         9      G      1.759355E-20   0.0            -3.265708E-04  0.0            -1.350967E-05  0.0
                        0.0            0.0             0.0           0.0             0.0           0.0
0        10      G      1.954835E-20   0.0            -1.129862E-04  0.0            -1.460182E-05  0.0
                        0.0            0.0             0.0           0.0             0.0           0.0
0        11      G      1.954833E-20   0.0            -2.218218E-04  0.0            -1.433058E-05  0.0
                        0.0            0.0             0.0           0.0             0.0           0.0
0        12      G      1.954833E-20   0.0            -2.218218E-04  0.0            -1.433058E-05  0.0
                        0.0            0.0             0.0           0.0             0.0           0.0
0        21      G      2.823239E-20   0.0             9.985832E-01  8.591962E-09   6.658700E-02  0.0
                        0.0            0.0             0.0           0.0             0.0           0.0
0        22      G      2.846085E-20   3.883373E-21    9.985833E-01  5.263812E-09   6.658700E-02  0.0
                        0.0            0.0             0.0           0.0             0.0           0.0
0        23      G      3.243097E-20   3.500366E-21    9.985833E-01  7.871622E-09   6.658700E-02  0.0
                        0.0            0.0             0.0           0.0             0.0           0.0
0        24      G      1.954833E-20   0.0            -2.218218E-04  0.0             6.658700E-02  0.0
                        0.0            0.0             0.0           0.0             0.0           0.0
0        25      G      3.058353E-20   1.292663E-21   -2.217712E-04  9.315126E-09   6.658700E-02  0.0
                        0.0            0.0             0.0           0.0             0.0           0.0
0        26      G      3.409665E-20   2.661906E-21   -2.216867E-04  7.387972E-09   6.658700E-02  0.0
                        0.0            0.0             0.0           0.0             0.0           0.0
0        27      G      2.889903E-20   0.0            -9.990268E-01  8.591684E-09   6.658700E-02  0.0
                        0.0            0.0             0.0           0.0             0.0           0.0
0        28      G      3.001179E-20  -7.144970E-21   -9.990268E-01  5.263531E-09   6.658700E-02  0.0
                        0.0            0.0             0.0           0.0             0.0           0.0
0        29      G      4.259531E-20  -9.221699E-21   -9.990267E-01  7.871339E-09   6.658700E-02  0.0
                        0.0            0.0             0.0           0.0             0.0           0.0
0        45      G      0.0            0.0            -8.080449E-04  0.0            -3.090406E-06  0.0
                        0.0            0.0             0.0           0.0             0.0           0.0
0        49      S      6.660133E-02
                        0.0

      COMPLEX EIGENVALUE = -2.666099E+02,  2.692103E+02
                                 C O M P L E X   E I G E N V E C T O R   NO.         9
                                                 (REAL/IMAGINARY)

      POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
0         1      G      0.0            0.0             1.567314E-03  0.0             8.767865E-05  0.0
                        0.0            0.0            -6.631188E-04  0.0            -9.979350E-06  0.0
0         2      G      0.0            0.0             2.619385E-04  0.0             8.571776E-05  0.0
                        0.0            0.0            -5.414258E-04  0.0            -4.379914E-06  0.0
0         3      G      0.0            0.0            -9.748650E-04  0.0             7.788606E-05  0.0
                        0.0            0.0            -5.246320E-04  0.0            -1.983666E-07  0.0
0         4      G      0.0            0.0            -2.026636E-03  0.0             6.045294E-05  0.0
                        0.0            0.0            -4.159614E-04  0.0            -1.991950E-05  0.0
0         5      G      2.227713E-21   0.0            -2.727064E-03  0.0             3.074192E-05  0.0
                       -1.017078E-22   0.0             1.766401E-04  0.0            -6.037806E-05  0.0
0         6      G      6.683128E-21   0.0            -2.889390E-03  0.0            -1.086977E-05  0.0
                       -3.051256E-22   0.0             1.287063E-03  0.0            -7.917323E-05  0.0
0         7      G      1.113853E-20   0.0            -2.369187E-03  0.0            -5.883813E-05  0.0
                       -5.085323E-22   0.0             2.221337E-03  0.0            -3.186847E-05  0.0
0         8      G      1.559396E-20   0.0            -1.144966E-03  0.0            -1.026627E-04  0.0
                       -7.119556E-22   0.0             1.942164E-03  0.0             7.562694E-05  0.0
0         9      G      2.004934E-20   0.0             6.344171E-04  0.0            -1.312320E-04  0.0
                       -9.153440E-22   0.0            -3.509332E-05  0.0             1.806468E-04  0.0
0        10      G      2.227701E-20   0.0             2.694578E-03  0.0            -1.403727E-04  0.0
                       -1.017057E-21   0.0            -3.158032E-03  0.0             2.219220E-04  0.0
0        11      G      2.227699E-20   0.0             1.647427E-03  0.0            -1.381149E-04  0.0
                       -1.017069E-21   0.0            -1.519293E-03  0.0             2.116517E-04  0.0
0        12      G      2.227699E-20   0.0             1.647427E-03  0.0            -1.381149E-04  0.0
                       -1.017069E-21   0.0            -1.519293E-03  0.0             2.116517E-04  0.0
0        21      G      3.237259E-20   0.0             1.000078E+00  1.306072E-07   6.656206E-02  0.0
                       -3.157529E-21   0.0            -1.215181E-03 -2.312141E-07   2.028463E-05  0.0
0        22      G      3.243294E-20   4.332363E-21    1.000080E+00  8.001252E-08   6.656211E-02  0.0
                       -3.410401E-21  -1.072529E-21   -1.217114E-03 -1.416640E-07   2.020964E-05  0.0
0        23      G      3.700661E-20   3.985483E-21    1.000081E+00  1.196552E-07   6.656207E-02  0.0
                       -3.757872E-21  -8.378306E-22   -1.218912E-03 -2.118374E-07   2.027174E-05  0.0
0        24      G      2.227699E-20   0.0             1.647427E-03  0.0             6.656206E-02  0.0
                       -1.017069E-21   0.0            -1.519293E-03  0.0             2.028257E-05  0.0
0        25      G      3.504104E-20   1.606656E-21    1.648196E-03  1.416024E-07   6.656206E-02  0.0
                       -3.421607E-21  -7.893717E-22   -1.520653E-03 -2.506663E-07   2.028257E-05  0.0
0        26      G      3.877015E-20   2.938605E-21    1.649481E-03  1.123036E-07   6.656206E-02  0.0
                       -4.773527E-21  -1.612552E-21   -1.522929E-03 -1.988203E-07   2.028257E-05  0.0
0        27      G      3.273195E-20   0.0            -9.967835E-01  1.306039E-07   6.656207E-02  0.0
                       -1.989708E-21   0.0            -1.823659E-03 -2.312032E-07   2.028052E-05  0.0
0        28      G      3.387519E-20  -7.772914E-21   -9.967824E-01  8.000918E-08   6.656202E-02  0.0
                       -1.048696E-21   3.150965E-21   -1.825591E-03 -1.416529E-07   2.035550E-05  0.0
0        29      G      4.958540E-20  -9.913153E-21   -9.967814E-01  1.196518E-07   6.656206E-02  0.0
                       -1.177094E-20   7.083269E-21   -1.827389E-03 -2.118262E-07   2.029340E-05  0.0
0        45      G      0.0            0.0            -2.432558E-03  0.0             4.724403E-05  0.0
                        0.0            0.0            -1.955204E-04  0.0            -3.918576E-05  0.0
0        49      S      6.670018E-02
                       -1.913691E-04
```

```
 COMPLEX EIGENVALUE = -4.402915E+02,  0.000000E+00
                                               C O M P L E X   E I G E N V E C T O R   NO.        10
                                                                 (REAL/IMAGINARY)

      POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
0          1      G      0.0            0.0            6.557046E-04   0.0            5.076228E-05   0.0
                         0.0            0.0            0.0            0.0            0.0            0.0
0          2      G      0.0            0.0           -4.929134E-05   0.0            3.947462E-05   0.0
                         0.0            0.0            0.0            0.0            0.0            0.0
0          3      G      0.0            0.0           -4.955510E-04   0.0            2.159035E-05   0.0
                         0.0            0.0            0.0            0.0            0.0            0.0
0          4      G      0.0            0.0           -8.212721E-04   0.0            2.856014E-05   0.0
                         0.0            0.0            0.0            0.0            0.0            0.0
0          5      G      2.114175E-21   0.0           -1.490145E-03   0.0            6.308790E-05   0.0
                         0.0            0.0            0.0            0.0            0.0            0.0
0          6      G      6.342518E-21   0.0           -2.613037E-03   0.0            7.744115E-05   0.0
                         0.0            0.0            0.0            0.0            0.0            0.0
0          7      G      1.057084E-20   0.0           -3.439931E-03   0.0            1.710460E-05   0.0
                         0.0            0.0            0.0            0.0            0.0            0.0
0          8      G      1.479922E-20   0.0           -2.774630E-03   0.0           -1.135409E-04   0.0
                         0.0            0.0            0.0            0.0            0.0            0.0
0          9      G      1.902752E-20   0.0           -5.127365E-05   0.0           -2.406725E-04   0.0
                         0.0            0.0            0.0            0.0            0.0            0.0
0         10      G      2.114167E-20   0.0            4.059213E-03   0.0           -2.906541E-04   0.0
                         0.0            0.0            0.0            0.0            0.0            0.0
0         11      G      2.114166E-20   0.0            1.910400E-03   0.0           -2.782170E-04   0.0
                         0.0            0.0            0.0            0.0            0.0            0.0
0         12      G      2.114166E-20   0.0            1.910400E-03   0.0           -2.782170E-04   0.0
                         0.0            0.0            0.0            0.0            0.0            0.0
0         21      G      3.261321E-20   0.0            1.000289E+00   2.778653E-07   6.655854E-02   0.0
                         0.0            0.0            0.0            0.0            0.0            0.0
0         22      G      3.306370E-20   5.189878E-21   1.000291E+00   1.702418E-07   6.655863E-02   0.0
                         0.0            0.0            0.0            0.0            0.0            0.0
0         23      G      3.751204E-20   4.534566E-21   1.000293E+00   2.545756E-07   6.655856E-02   0.0
                         0.0            0.0            0.0            0.0            0.0            0.0
0         24      G      2.114166E-20   0.0            1.910400E-03   0.0            6.655854E-02   0.0
                         0.0            0.0            0.0            0.0            0.0            0.0
0         25      G      3.531220E-20   2.317721E-21   1.912034E-03   3.012458E-07   6.655854E-02   0.0
                         0.0            0.0            0.0            0.0            0.0            0.0
0         26      G      4.035677E-20   4.643557E-21   1.914769E-03   2.389329E-07   6.655854E-02   0.0
                         0.0            0.0            0.0            0.0            0.0            0.0
0         27      G      3.179479E-20   0.0           -9.964676E-01   2.778536E-07   6.655854E-02   0.0
                         0.0            0.0            0.0            0.0            0.0            0.0
0         28      G      3.170185E-20  -1.086609E-20  -9.964653E-01   1.702300E-07   6.655845E-02   0.0
                         0.0            0.0            0.0            0.0            0.0            0.0
0         29      G      5.764113E-20  -1.746216E-20  -9.964631E-01   2.545637E-07   6.655853E-02   0.0
                         0.0            0.0            0.0            0.0            0.0            0.0
0         45      G      0.0            0.0           -1.090969E-03   0.0            4.397528E-05   0.0
                         0.0            0.0            0.0            0.0            0.0            0.0
0         49      S      6.683676E-02
                         0.0
```

Aeroservoelastic Stability Analysis of a Missile (Example HA145J)

In this example, the aerodynamic forces are added to the previous Example HA110A (p. 580). The additional Bulk Data entries beyond those required to solve the servoelastic stability problem provide the aerodynamic, spline, and flutter data and are shown in Listing 8-43. The input files struct.dat and servo.dat (see Listing 8-39 and Listing 8-40) are INCLUDEd as before. The AERO entry gives the reference chord of 30.0 in., the reference density at sea level of $1.1468\text{E-07 lb-sec}^2/\text{in}^4$, and specifies symmetry. CAERO1 101 divides the flipper semispan (see Figure 8-20) into 10 equal width strips and 15 equal chordwise segments on each strip to satisfy the guidelines of Interpolation from Structural to Aerodynamic Models that the box chord $\Delta x \le 0.08 V/f$ where V is the minimum velocity of interest (500 ft/s) and f is the maximum frequency of interest (251 Hz) and that the box aspect ratios be less than 3. The CAERO1 continuation lists the coordinates of the leading edge at the root and tip and the root and tip chord lengths. PAERO1 1 defines the fuselage as the associated body that is described on CAERO2 and PAERO2 entries. CAERO2 1500 specifies the body characteristics on PAERO2 1520, the fractional divisions of the body on AEFACT 1505, the fractional divisions of the interference body on AEFACT 1506, and the body nose coordinates and length on the continuation entry. PAERO2 1520 provides data on the motion (in the z-direction for vertical motion), the reference half-width of the body (a representative value is recommended in the region of the lifting surface root), the aspect ratio (height/width) of the cross section approximated as an ellipse (AR = 1.0 in this example with a circular cross section), and AEFACT 1515 for the body half-widths at the end points given on AEFACT 1505. The PAERO2 field LRIB is left blank following the recommendation in Aerodynamic Modeling. The PAERO2 entry also specifies the θ_1 - and θ_2 -arrays for averaging the downwash on the interference body that is induced by the lifting surface bound vortices and doublets in the approximation to satisfy the no-flow condition through the body surface (only a θ_1 -array is specified here on AEFACT 1518 at $\theta = 45°$, $135°$, $225°$, and $315°$, which are angles spaced midway between adjacent flippers in the cruciform configuration. The PAERO2 continuation specifies that all the interference elements use the θ_1 -array.

Linear spline entries are used to connect the aerodynamics and the structure along the hinge line at the midchord of the flipper and along the fuselage centerline. SPLINE2 1 connects the 150 aerodynamic boxes (numbers 101 through 250) to GRIDs 21 through 23 along the leading edge and GRIDs 27 through 29 along the trailing edge on the SET1 1 entry. The axis of the spline along the hinge line is the y-axis of CORD2R 1. The spline attachment flexibility is not used so DZ = 0.0, and no rotational connection to the flipper grid points is considered so DTHX = DTHY = -1.0; since DZ = 0.0, DTOR is arbitrarily set to 1.0. SPLINE2 2 connects the six body aerodynamic elements (numbers 1500 through 1505) to GRIDs 1 through 10 on SET1 2. The attachment flexibilities are DZ = 0.0 and DTHY = 0.0 for both displacement and rotational spline connections, DTOR = 1.0 (always for bodies). DTHX is not used for bodies.

For the vibration analysis, the modified Householder method (MHOU) is requested on the EIGR entry as before, and six vibration modes are again used in the modal formulation, PARAM,LMODES,6. PARAM,OPPHIPA,1, along with a DISP command in the Case Control Section, specifies the eigenvectors at both the structural and aerodynamic grid points.

Main Index

The values of Mach number and reduced frequency that provide the basis for interpolation are specified on MKAEROi entries. In this case, the MKAERO1 entry is selected for one Mach number, $m = 0.8$, and six reduced frequencies, $k = 0.001$, 0.1, 0.2, 0.5, 1.0, and 4.0, are specified to cover the range required by the velocities and frequencies of interest.

The flutter data entries include FLFACT 1, which gives the density ratio of 1.0; FLFACT 2, which gives the Mach number 0.8; and FLFACT 3, which lists six velocities for the aeroservoelastic stability analysis ranging from 6000 to 12000 in/s. The first velocity is input as negative to obtain eigenvectors in addition to eigenvalues in the PK-method of solution. FLUTTER 40 specifies the PK-method of flutter analysis, refers to the FLFACT entries, and requests output for 11 modes. Eleven roots are requested for the system of three rigid and three flexible body roots and the five extra points. The last flutter data entry is PARAM,VREF to convert the output velocity units from in/s to ft/s by dividing by 12.0. The ENDDATA entry completes the Bulk Data Section.

Case Control Section

The Case Control Section shown in Listing 8-43 is changed for the flutter analysis from what was required in the servoelastic analysis. New title commands are used. The FMETHOD command replaces the CMETHOD command when the PK-method is specified for flutter analysis. Specifying SET1 = 1 through 2000, which includes all aerodynamic degrees of freedom, along with DISP requests modal displacements. The last command in the Case Control Section is BEGIN BULK.

The Executive Control Section starts with the identification ID MSC, HA145J. It then specifies TIME 5 for 30.0 minutes of CPU time and SOL 145 for the Superelement Aerodynamic Flutter DMAP sequence. The CEND statement completes the Executive Control Section.

Output

Selected items that have been extracted from the f06 file in the printed output are shown in Listing 8-44. The significant results are discussed here. The first output shown is the result of the vibration analysis: the first six frequencies, the generalized masses, and stiffnesses. These are the same as shown in Listing 8-43 in the previous section (except for round-off differences between SOLs 110 and 145). The next output shown is a representative real eigenvector, the fourth mode that is the first fuselage bending mode, and includes the SPOINT, EPOINT, and all aerodynamic grid point displacements. Following the typical real eigenvector is a series of representative eigenvalues and modal eigenvectors (participation factors) for the flutter modes that were requested by the negative velocity $V = -6000 \text{ in/s} = -500 \text{ ft/s}$. Shown are the two actuator modes, the short period mode, the gyro mode, and three vibration modes. Also shown, for all of the velocities, are the zero frequency roots that are not listed in the Flutter Summary tables. The aerodynamic forces in this example have very little effect on the servoelastic system. The roots (shown next in the Flutter Summary tables) are changed only slightly from the previous Example HA110A (p. 580), except for the rigid body pitch mode, which has become the short period mode and appears as Point 3 in the Flutter Summary tables.

The PK-method of flutter analysis provides a solution for the short period mode whereas the K-method does not. With the flipper locked (by using scalar spring CELAS2 1 shown in the Bulk Data of Listing 8-43; results are not listed) the short period of the missile is lightly damped and has a constant reduced frequency

$k = 0.0186$ for the range of airspeed from $V = 500$ to 1000 ft/s . Its frequency increases from $f = 1.183$ to 2.362 Hz , and its damping is constant at $g = 2\zeta = 0.2708$. The purpose of the servo system is to increase the short period damping substantially. A reasonably well damped short period throughout the speed range of interest is obtained by adjusting the gyro gain to $K_g = 0.13$ deg per deg/s, and this is the design consideration that determines K_g . In the Flutter Summary for Point 3, the damping and frequency at $V = 500$ ft/s are $g = 1.945$ and $f = 0.961$ Hz and at $V = 1000$ ft/s the damping has decreased to $g = 1.316$ and the frequency has increased to $f = 5.821$ Hz .

The short period characteristics in Point 3 of the Flutter Summary are the data of primary interest in this analysis. However, the other Points also deserve some comment. Point 4 is the gyro mode, which is unaffected by the airstream. Points 5 through 7 are the three fuselage modes and their frequencies are unaffected and their dampings are only slightly affected by the airstream. Point 8 is the artificial actuator/flipper transfer function mode, and the output indicating instability is meaningless. Finally, Point 2 is the rigid body plunge mode that should also have a zero frequency, even in the presence of the airstream; the nonzero frequencies shown are round-off errors that result from the MSC Nastran formulation using plunge and pitch (h, α) degrees of freedom rather than pitch and pitch rate (α, q) degrees of freedom in the equations of motion. The positive dampings shown should not be interpreted as instabilities.

The data following the Flutter Summary tables are the complex eigenvectors of grid point deflections that were also generated by the negative velocity in the Bulk Data Section and the DISPlacement command in the Case Control Section.

Listing 8-43 Input Files for Aeroservoelastic Stability Analysis of a Missile

```
$$$$$$$$     HANDBOOK FOR AEROELASTIC ANALYSIS EXAMPLE HA145J   $$$$$$$$
$                                                                      $
$       MODEL DESCRIPTION        TYPICAL AIR-TO-AIR MISSILE -          $
$                                BAR MODEL WITH 10 FUSELAGE STATIONS   $
$                                AND AN ACTIVE CONTROLS SYSTEM.        $
$                                                                      $
$       SOLUTION                 PK FLUTTER ANALYSIS METHOD USING      $
$                                DOUBLET-LATTICE METHOD AERODYNAMICS   $
$                                ON THE FLIPPERS AND SLENDER BODY      $
$                                AERODYNAMICS ON THE BODY              $
$                                                                      $
$                                                                      $
$$$$$$$$                                                        $$$$$$$$
TIME 30 $ TIME IN CPU MINUTES
SOL 145 $ FLUTTER ANALYSIS
CEND

TITLE = EXAMPLE HA145J: FLEXIBLE MISSILE WITH CONTROL SYSTEM   HA145J
SUBTI = SYMMETRIC FLIPPER AND BODY MOTIONS, DOUBLET-LATTICE AERO
LABEL = HALF-SPAN MODEL, PK FLUTTER ANALYSIS
  ECHO    = BOTH
  MPC     = 50
  SDAMP   = 1        $ MODAL DAMPING
  TFL     = 1        $ SERVO TRANSFER FUNCTION
  METHOD  = 14       $ MODIFIED HOUSEHOLDER REAL EIGENVALUE EXTRACTION METHOD
  FMETHOD = 40       $ PK-FLUTTER METHOD
  SET 1   = 1 THRU 2000
  DISP    = 1
BEGIN BULK
$*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
$                                                                         $
$       THE ANNOTATIONS IN THIS INPUT DECK ARE INTENDED TO                $
$       EXPLAIN THE DATA ON THE CARD IMAGES FOR THIS SPECIFIC             $
$       EXAMPLE WITHOUT REFERENCE TO THE VARIOUS MANUALS WHERE            $
$       MORE GENERAL DEFINITIONS WILL BE FOUND.                           $
$                                                                         $
$*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
$                                                                         $
INCLUDE 'struct.dat'
$
$        SPRING FOR LOCKING FLIPPER ROTATION
$
$       EID     K       G1      C1      G2      C2      GE      S
$CELAS2 1       1.0+10  12      5       24      5
$
INCLUDE 'servo.dat'
$
$        THE AERO CARD SPECIFIES THE AERO COORDINATE SYSTEM, THE          $
$        REFERENCE LENGTHS PLUS SYMMETRY KEYS.  SYMXZ = 0 INDICATES       $
$        THAT THE MODEL IS MOUNTED WITH NO ROOT REFLECTION PLANE;         $
$        SYMXY = 0 INDICATES THAT THE MODEL IS MOUNTED FAR ENOUGH         $
$        FROM THE FLOOR SO THAT REFLECTION EFFECTS ARE NEGLIGIBLE.        $
$                                                                         $
$       ACSID   VELOCITY REFC   RHOREF  SYMXZ   SYMXY
AERO                    30.0    1.1468-71
$                                                                         $
$        THE CAERO1 CARD IS USED FOR DOUBLET LATTICE AERODYNAMICS.        $
$        LISTED ARE ITS PAERO CARD ID AND THE COORDINATE SYSTEM           $
$        FOR LOCATING THE INBOARD AND OUTBOARD LEADING EDGE POINTS        $
$        (1 AND 4).  NSPAN AND NCHORD, OR LSPAN AND LCHORD, ARE           $
$        USED TO PARTITION THE WING INTO AERODYNAMIC PANELS.              $
$        THE FORMER FOR UNIFORMLY SPACED PANELS AND THE LATTER            $
$        FOR NON-UNIFORMLY SPACED PANELS.  IGID IS THE ID OF ITS          $
$        ASSOCIATED INTERFERENCE GROUP.  THE CONTINUATION CARD            $
$        DEFINES POINTS 1 AND 4, THE ROOT CHORD AND TIP CHORD.            $
$        THE BOXES FORMED BY THE GRID LINES WILL BE NUMBERED              $
$        BEGINNING WITH EID SO CHOOSE A NUMBER THAT IS UNIQUE,            $
$        AND IS GREATER THAN ALL STRUCTURAL GRID, SCALAR AND              $
$        EXTRA POINT IDS.                                                 $
$                                                                         $
$       EID     PID     CP      NSPAN   NCHORD  LSPAN   LCHORD  IGID    +CONT
CAERO1  101     1               10      15                      1       +CA1
$      ( FWD LEFT POINT  )   ROOTCHORD ( FWD RIGHT POINT  )  TIP CHORD
$       X1      Y1      Z1      X12     X4        Y4    Z4      X14
+CA1    60.0    10.0    0.0     30.0    60.0    30.0    0.0     30.0
$                                                                         $
```

Listing 8-43 Input Files for Aeroservoelastic Stability Analysis of a Missile (Continued)

```
$        THE PAERO1 CARD DEFINES CAERO2 CARDS THAT DEFINE ASSOCIATED    $
$        BODIES.                                                        $
$                                                                       $
$       PID     B1      B2      B3      ETC
PAERO1  1       1500
$                                                                       $
$        THE CAERO2 CARD DEFINES AN AERODYNAMIC BODY FOR DOUBLET-       $
$        LATTICE AERODYNAMICS.  IT LISTS ITS PAERO2 CARD, THE           $
$        COORDINATE SYSTEM FOR LOCATING POINT 1 AT THE NOSE OF THE      $
$        BODY, THE NUMBER OF UNIFORM SLENDER BODY AND INTERFERENCE      $
$        ELEMENTS, OR IF NON-UNIFORM IT IDENTIFIES AEFACT CARDS ON      $
$        WHICH THE ELEMENTS ARE DEFINED, AND IT IDENTIFIES THE          $
$        ASSOCIATED INTERFERENCE GROUP.  THE CONTINUATION CARD LISTS    $
$        THE COORDINATES OF THE NOSE POINT AND THE LENGTH OF THE BODY.  $
$                                                                       $
$       EID     PID     CP      NSB     NINT    LSB     LINT    IGID    +CONT
CAERO2  1500    1520                            1505    1506    1       +CA2
$       X1      Y1      Z1      X12
+CA2    -60.0   0.0     0.0     150.0
$                                                                       $
$       SID     D1      D2      D3      ETC
AEFACT  1505    0.0     0.1     0.2     0.4     0.6     0.8     1.0
AEFACT  1506    .6      .8      1.
$                                                                       $
$        THE PAERO2 CARD DEFINES THE CROSS-SECTION PROPERTIES OF        $
$        AERODYNAMIC BODIES.  IT LISTS THE ORIENTATION OF MOTION        $
$        OF THE BODY, ITS HALF-WIDTH AND ASPECT RATIO (HEIGHT/          $
$        WIDTH), IDENTIFIES AEFACT CARDS FOR ADDITIONAL DATA AND        $
$        IDENTIFIES THE FIRST AND LAST INTERFERENCE ELEMENTS OF THE     $
$        BODY TO USE THE THETA ARRAYS DESIGNATED BY LTH1 AND LTH2.      $
$                                                                       $
$       PID     ORIENT  WIDTH   AR      LRSB    LRIB    LTH1    LTH2
PAERO2  1520    Z       10.0    1.0     1515            1518            +PA2
$       THI1    THN1    THI2    THN2
+PA2    1       2
$                                                                       $
$               (LRSB)  SLENDER BODY HALF-WIDTHS                        $
$                                                                       $
$       SID     D1      D2      D3      D4      D5      D6      D7
AEFACT  1515    0.0     10.0    10.0    10.0    10.0    10.0    10.0
$                                                                       $
$               (LTH1 AND 2)  THETA ARRAYS                              $
$                                                                       $
$        THETA IS A POSITIVE ROTATION ABOUT THE X-AXIS, SO 0. LIES      $
$        AT THE JUNCTURE OF THE FLIPPER AND THE BODY.                   $
$                                                                       $
$       SID     D1      D2      D3      D4      ETC
AEFACT  1518    45.     135.    225.    315.
$                                                                       $
$                                                                       $
$        THE SPLINE2 CARD SPECIFIES A BEAM SPLINE FOR INTERPOLAT-       $
$        ION OVER THE REGION OF THE CAERO CARD (ID1 AND ID2 ARE         $
$        THE FIRST AND LAST BOXES IN THIS REGION).  SETG REFERS         $
$        TO A SET1 CARD WHERE THE STRUCTURAL GRID POINTS ARE            $
$        DEFINED.  DZ AND DTOR ARE SMOOTHING CONSTANTS FOR LINEAR       $
$        ATTACHMENT AND TORSIONAL FLEXIBILITIES.  DTHX AND DTHY         $
$        ARE ROTATIONAL ATTACHMENT FLEXIBILITIES. CID IDENTIFIES        $
$        THE CORD2R CARD THAT DEFINES THE SPLINE AXIS.                  $
$                                                                       $
$       EID     CAERO   ID1     ID2     SETG    DZ      DTOR    CID
SPLINE2 1       101     101     250     1       0.0     1.0     1       +SP1
$       DTHX    DTHY
+SP1    -1.0    -1.0
$                                                                       $
$        THE SET1 CARD DEFINES THE SETS OF STRUCTURAL GRID POINTS       $
$        TO BE USED BY THE BEAM SPLINE FOR INTERPOLATION.               $
$                                                                       $
$       SID     G1      G2      G3      ETC
SET1    1       21      22      23      27      28      29
$                                                                       $
$        THE CORD2R CARD DEFINES THE COORDINATE SYSTEM IN WHICH THE     $
$        BEAM SPLINE EXTENDS ALONG THE Y-AXIS.  IT LISTS THE ORIGIN,    $
$        A POINT ALONG THE Z-AXIS AND A POINT IN THE X-Z PLANE.  IN     $
$        THIS CASE, THE SPLINE AXIS IS ALIGNED WITH THE HINGE LINE.     $
$                                                                       $
$       CID     RID     A1      A2      A3      B1      B2      B3
CORD2R  1               75.0                    75.0            30.     +CR1
$       C1      C2      C3
+CR1    100.
$
```

Listing 8-43 Input Files for Aeroservoelastic Stability Analysis of a Missile (Continued)

```
$        THE NEXT CARD AND THE SET1 CARD IT SPECIFIES DEFINE A BEAM     $
$        SPLINE TO INTERPOLATE BETWEEN ELEMENTS 101 AND 109 ON          $
$        THE FUSELAGE.   CID DEFAULTS TO THE BASIC COORDINATE SYSTEM    $
$        WHICH DEFINES THE Y AXIS OF THE SPLINE AS COINCIDENT WITH      $
$        THE BASIC Y AXIS.  DZ, DTOR, DTHX AND DTHY ARE ATTACHMENT      $
$        FLEXIBILITIES WHICH, FOR BODIES, ARE TAKEN AS DTOR = 1.0       $
$        AND DTHX IS NOT USED.                                          $
$                                                                       $
$       EID     CAERO   ID1     ID2     SETG    DZ      DTOR    CID
SPLINE2 2       1500    1500    1505    2       0.0     1.0             +SP2
$       DTHX    DTHY
+SP2    -1.
$                                                                       $
$       SID     G1      G2      G2      ETC
SET1    2       1       THRU    10
$                                                                       $
$                                                                       $
$                    * * VIBRATION ANALYSIS * *                         $
$                                                                       $
$       SID     METHOD  F1      F2      NE      ND                      +EIG
EIGR    14      MHOU                            6                       +HOU
$+EIG   NORM    G       C
+HOU    MAX
$                                                                       $
$                      * VIBRATION MODES *                              $
$                                                                       $
$        THE PARAM, OPPHIPA = 1 (WHEN ACCOMPANIED BY A DISPLACEMENT     $
$        REQUEST IN THE CASE CONTROL DECK), WILL GENERATE THE VIBRA-    $
$        TION MODE DISPLACEMENTS FOR BOTH THE STRUCTURAL GRID POINTS    $
$        AND THE AERODYNAMIC GRID POINTS (BOX CENTERLINE MIDPOINTS)     $
$        IN THE OUTPUT.                                                 $
$                                                                       $
$       N       V1      V2
PARAM   OPPHIPA 1
$                                                                       $
$            * * * AEROSERVOELASTIC STABILITY ANALYSIS * * *            $
$                                                                       $
$        THE PARAM,LMODES,N CARD SPECIFIES THAT N VIBRATION MODES       $
$        ARE TO BE USED IN THE ANALYSIS.                                $
$                                                                       $
$       N       V1      V2                                              $
PARAM   LMODES  6
$                                                                       $
$                   * * AERODYNAMIC CONDITIONS * *                      $
$                                                                       $
$        ALL COMBINATIONS OF MACH NUMBER AND REDUCED FREQUENCY LISTED   $
$        ON THE MKAERO1 CARD AND ITS CONTINUATION CARD WILL BE USED     $
$        TO GENERATE GENERALIZED AERO FORCE MATRICES.  IF MORE THAN     $
$        EIGHT MACH NO.S OR REDUCED FREQUENCIES ARE REQUIRED A SECOND   $
$        MKAERO1 IS NECESSARY.                                          $
$                                                                       $
$        M1      M2      M3      ETC
MKAERO1 0.8                                                             +MKA
$        K1      K2      K3      K4      K5      ETC
+MKA    0.001   0.1     0.2     0.5     1.0     4.0
$                                                                       $
$                 * * FLUTTER SOLUTION PARAMETERS * *                   $
$                                                                       $
$        THE FLUTTER CARD DEFINES THE METHOD OF SOLUTION, IDENTIFIES    $
$        THE FLFACT CARDS THAT FOLL0W, SPECIFIES THE INTERPOLATION      $
$        METHOD, THE NUMBER OF ROOTS DESIRED IN THE OUTPUT AND THE      $
$        CRITERION FOR CONVERGENCE (DEFAULT IS 10-3).                   $
$                                                                       $
$       SID     METHOD  DENS    MACH    VEL     IMETH   NVALUE  EPS     $
FLUTTER 40      PK      1       2       3       L       11      0.01
$                                                                       $
$        FLFACT CARDS ARE USED TO SPECIFY DENSITY RATIOS, MACH NOS      $
$        AND REDUCED FREQUENCIES/VELOCITIES FOR FLUTTER ANALYSES.       $
$        NEGATIVE VELOCITIES ARE CODES TO COMPUTE AND PRINT EIGEN-      $
$        VECTORS.                                                       $
$                                                                       $
$       SID     F1      F2      F3      F4      F5      F6      F7      $
FLFACT  1       1.0
FLFACT  2       0.8
FLFACT  3       -6000.  7200.   8400.   9600.   10800.  12000.
$                                                                       $
$        THE PARAM,VREF,C CARD SPECIFIES A CONVERSION FACTOR TO BE      $
$        USED TO CONVERT THE DIMENSIONS OF THE OUTPUT VELOCITIES BY     $
$        DIVIDING BY C, IN THIS CASE BY 12.0 IN/FT TO PRINT VEL-        $
$        OCITIES IN FT/SEC RATHER THAN IN/SEC.                          $
$                                                                       $
$       N       V1      V2
PARAM   VREF    12.0
$                                                                       $
ENDDATA
```

Listing 8-44 Output for Aeroservoelastic Stability Analysis of a Missile

```
 *** USER INFORMATION MESSAGE 7588 (GKAM)
     BASED ON THE USER PARAMETERS LMODES, LFREQ OR HFREQ, ONLY        6 OF THE       10 COMPUTED STRUCTURE MODES
     (MODES       1 THROUGH       6) WILL BE USED IN THIS MODAL COMPLEX EIGENVALUE ANALYSIS
     (DETAILS OF THE EIGENVALUE DATA FOR THE MODES USED ARE GIVEN BELOW)
1    EXAMPLE HA145J: FLEXIBLE MISSILE WITH CONTROL SYSTEM    HA145J          APRIL  11, 2019  MSC Nastran  4/11/19   PAGE    27
      SYMMETRIC FLIPPER AND BODY MOTIONS, DOUBLET-LATTICE AERO
0     HALF-SPAN MODEL, PK FLUTTER ANALYSIS

                                          R E A L   E I G E N V A L U E S
                                     (ACTUAL MODES USED IN THE DYNAMIC ANALYSIS)
   MODE    EXTRACTION      EIGENVALUE            RADIANS             CYCLES            GENERALIZED         GENERALIZED
    NO.       ORDER                                                                       MASS              STIFFNESS
        1         1        1.261360E-07        3.551563E-04        5.652488E-05        1.632621E-01        2.059323E-08
        2         2        3.550667E-09        5.958748E-05        9.483641E-06        4.326820E-01        1.536310E-09
        3         3        4.399742E-06        2.097556E-03        3.338365E-04        4.296136E-03        1.890189E-08
        4         4        8.055727E+04        2.838261E+02        4.517233E+01        5.257575E-01        4.235359E+04
        5         5        6.341576E+05        7.963401E+02        1.267415E+02        7.764813E-01        4.924115E+05
        6         6        2.487909E+06        1.577311E+03        2.510368E+02        7.707402E-01        1.917532E+06

      EIGENVALUE =  8.055727E+04
          CYCLES =  4.517233E+01         R E A L   E I G E N V E C T O R   N O .          4

      POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
             1      G      0.0            0.0            1.000000E+00   0.0            3.957338E-02   0.0
             2      G      0.0            0.0            4.148083E-01   0.0            3.789159E-02   0.0
             3      G      0.0            0.0           -1.164419E-01   0.0            3.214863E-02   0.0
             4      G      0.0            0.0           -5.268358E-01   0.0            2.184270E-02   0.0
             5      G      9.534943E-20   0.0           -7.543173E-01   0.0            8.055652E-03   0.0
             6      G      2.860477E-19   0.0           -7.618729E-01   0.0           -7.057891E-03   0.0
             7      G      4.767434E-19   0.0           -5.486976E-01   0.0           -2.094803E-02   0.0
             8      G      6.674403E-19   0.0           -1.505695E-01   0.0           -3.141066E-02   0.0
             9      G      8.581318E-19   0.0            3.706048E-01   0.0           -3.726979E-02   0.0
            10      G      9.534789E-19   0.0            9.466013E-01   0.0           -3.895796E-02   0.0
            11      G      9.534783E-19   0.0            6.554547E-01   0.0           -3.854272E-02   0.0
            12      G      9.534783E-19   0.0            6.554547E-01   0.0           -3.854272E-02   0.0
            21      G      1.428186E-18   0.0            5.243272E-01   3.241577E-05  -8.743307E-03   0.0
            22      G      1.347365E-18   1.300965E-19   5.245981E-01   1.985664E-05  -8.732798E-03   0.0
            23      G      1.550126E-18   1.480092E-19   5.248501E-01   2.969630E-05  -8.741509E-03   0.0
            24      G      9.534783E-19   0.0            6.554547E-01   0.0           -8.743030E-03   0.0
            25      G      1.533107E-18   1.089846E-19   6.556454E-01   3.514602E-05  -8.743030E-03   0.0
            26      G      1.553073E-18   7.483244E-20   6.559645E-01   2.787199E-05  -8.743030E-03   0.0
            27      G      1.325735E-18   0.0            7.866181E-01   3.241549E-05  -8.742753E-03   0.0
            28      G      1.328370E-18  -1.299167E-19   7.868890E-01   1.985636E-05  -8.753262E-03   0.0
            29      G      2.284375E-18  -2.849001E-20   7.871410E-01   2.969602E-05  -8.744550E-03   0.0
            45      G      0.0            0.0           -6.664272E-01   0.0            1.527356E-02   0.0
            49      S      2.979969E-02

      EIGENVALUE =  8.055727E+04
          CYCLES =  4.517233E+01         R E A L   E I G E N V E C T O R   N O .          4

      POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
           101      G      0.0            0.0            5.330978E-01   0.0           -8.743030E-03   0.0
           102      G      0.0            0.0            5.505838E-01   0.0           -8.743030E-03   0.0
           103      G      0.0            0.0            5.680699E-01   0.0           -8.743030E-03   0.0
           104      G      0.0            0.0            5.855559E-01   0.0           -8.743030E-03   0.0
           105      G      0.0            0.0            6.030420E-01   0.0           -8.743030E-03   0.0
           106      G      0.0            0.0            6.205281E-01   0.0           -8.743030E-03   0.0
           107      G      0.0            0.0            6.380141E-01   0.0           -8.743030E-03   0.0
           108      G      0.0            0.0            6.555002E-01   0.0           -8.743030E-03   0.0
           109      G      0.0            0.0            6.729862E-01   0.0           -8.743030E-03   0.0
           110      G      0.0            0.0            6.904723E-01   0.0           -8.743030E-03   0.0
           111      G      0.0            0.0            7.079584E-01   0.0           -8.743030E-03   0.0
           112      G      0.0            0.0            7.254444E-01   0.0           -8.743030E-03   0.0
           113      G      0.0            0.0            7.429305E-01   0.0           -8.743030E-03   0.0
           114      G      0.0            0.0            7.604165E-01   0.0           -8.743030E-03   0.0
           115      G      0.0            0.0            7.779026E-01   0.0           -8.743030E-03   0.0
           116      G      0.0            0.0            5.331528E-01   0.0           -8.743030E-03   0.0
           117      G      0.0            0.0            5.506388E-01   0.0           -8.743030E-03   0.0
           118      G      0.0            0.0            5.681249E-01   0.0           -8.743030E-03   0.0
           119      G      0.0            0.0            5.856110E-01   0.0           -8.743030E-03   0.0
           120      G      0.0            0.0            6.030970E-01   0.0           -8.743030E-03   0.0
           121      G      0.0            0.0            6.205831E-01   0.0           -8.743030E-03   0.0
           122      G      0.0            0.0            6.380691E-01   0.0           -8.743030E-03   0.0
           123      G      0.0            0.0            6.555552E-01   0.0           -8.743030E-03   0.0
           124      G      0.0            0.0            6.730413E-01   0.0           -8.743030E-03   0.0
           125      G      0.0            0.0            6.905273E-01   0.0           -8.743030E-03   0.0
           126      G      0.0            0.0            7.080134E-01   0.0           -8.743030E-03   0.0
           127      G      0.0            0.0            7.254994E-01   0.0           -8.743030E-03   0.0
           128      G      0.0            0.0            7.429855E-01   0.0           -8.743030E-03   0.0
           129      G      0.0            0.0            7.604716E-01   0.0           -8.743030E-03   0.0
           130      G      0.0            0.0            7.779576E-01   0.0           -8.743030E-03   0.0
           131      G      0.0            0.0            5.332075E-01   0.0           -8.743030E-03   0.0
           132      G      0.0            0.0            5.506935E-01   0.0           -8.743030E-03   0.0
           133      G      0.0            0.0            5.681796E-01   0.0           -8.743030E-03   0.0
           134      G      0.0            0.0            5.856656E-01   0.0           -8.743030E-03   0.0
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Listing 8-44 Output for Aeroservoelastic Stability Analysis of a Missile (Continued)

```
 135      G      0.0          0.0           6.031517E-01   0.0         -8.743030E-03   0.0
          136      G      0.0          0.0           6.206378E-01   0.0         -8.743030E-03   0.0
          137      G      0.0          0.0           6.381238E-01   0.0         -8.743030E-03   0.0
          138      G      0.0          0.0           6.556099E-01   0.0         -8.743030E-03   0.0
          139      G      0.0          0.0           6.730959E-01   0.0         -8.743030E-03   0.0
          140      G      0.0          0.0           6.905820E-01   0.0         -8.743030E-03   0.0
          141      G      0.0          0.0           7.080681E-01   0.0         -8.743030E-03   0.0
          142      G      0.0          0.0           7.255541E-01   0.0         -8.743030E-03   0.0
          143      G      0.0          0.0           7.430402E-01   0.0         -8.743030E-03   0.0
          144      G      0.0          0.0           7.605262E-01   0.0         -8.743030E-03   0.0
          145      G      0.0          0.0           7.780123E-01   0.0         -8.743030E-03   0.0
          146      G      0.0          0.0           5.332616E-01   0.0         -8.743030E-03   0.0
          147      G      0.0          0.0           5.507476E-01   0.0         -8.743030E-03   0.0
          148      G      0.0          0.0           5.682337E-01   0.0         -8.743030E-03   0.0
          149      G      0.0          0.0           5.857197E-01   0.0         -8.743030E-03   0.0
          150      G      0.0          0.0           6.032058E-01   0.0         -8.743030E-03   0.0
          151      G      0.0          0.0           6.206919E-01   0.0         -8.743030E-03   0.0
          152      G      0.0          0.0           6.381779E-01   0.0         -8.743030E-03   0.0
          153      G      0.0          0.0           6.556640E-01   0.0         -8.743030E-03   0.0
          154      G      0.0          0.0           6.731500E-01   0.0         -8.743030E-03   0.0
          155      G      0.0          0.0           6.906361E-01   0.0         -8.743030E-03   0.0
          156      G      0.0          0.0           7.081222E-01   0.0         -8.743030E-03   0.0
          157      G      0.0          0.0           7.256082E-01   0.0         -8.743030E-03   0.0
          158      G      0.0          0.0           7.430943E-01   0.0         -8.743030E-03   0.0
          159      G      0.0          0.0           7.605803E-01   0.0         -8.743030E-03   0.0
          160      G      0.0          0.0           7.780664E-01   0.0         -8.743030E-03   0.0
          161      G      0.0          0.0           5.333149E-01   0.0         -8.743030E-03   0.0
          162      G      0.0          0.0           5.508009E-01   0.0         -8.743030E-03   0.0
          163      G      0.0          0.0           5.682870E-01   0.0         -8.743030E-03   0.0
          164      G      0.0          0.0           5.857731E-01   0.0         -8.743030E-03   0.0
          165      G      0.0          0.0           6.032591E-01   0.0         -8.743030E-03   0.0
          166      G      0.0          0.0           6.207452E-01   0.0         -8.743030E-03   0.0
          167      G      0.0          0.0           6.382312E-01   0.0         -8.743030E-03   0.0
          168      G      0.0          0.0           6.557173E-01   0.0         -8.743030E-03   0.0
          169      G      0.0          0.0           6.732034E-01   0.0         -8.743030E-03   0.0
          170      G      0.0          0.0           6.906894E-01   0.0         -8.743030E-03   0.0
          171      G      0.0          0.0           7.081755E-01   0.0         -8.743030E-03   0.0
          172      G      0.0          0.0           7.256615E-01   0.0         -8.743030E-03   0.0
          173      G      0.0          0.0           7.431476E-01   0.0         -8.743030E-03   0.0
          174      G      0.0          0.0           7.606337E-01   0.0         -8.743030E-03   0.0
          175      G      0.0          0.0           7.781197E-01   0.0         -8.743030E-03   0.0
          176      G      0.0          0.0           5.333672E-01   0.0         -8.743030E-03   0.0
          177      G      0.0          0.0           5.508532E-01   0.0         -8.743030E-03   0.0
          178      G      0.0          0.0           5.683393E-01   0.0         -8.743030E-03   0.0
          179      G      0.0          0.0           5.858253E-01   0.0         -8.743030E-03   0.0
          180      G      0.0          0.0           6.033114E-01   0.0         -8.743030E-03   0.0
          181      G      0.0          0.0           6.207975E-01   0.0         -8.743030E-03   0.0
          182      G      0.0          0.0           6.382835E-01   0.0         -8.743030E-03   0.0
          183      G      0.0          0.0           6.557696E-01   0.0         -8.743030E-03   0.0
          184      G      0.0          0.0           6.732556E-01   0.0         -8.743030E-03   0.0
          185      G      0.0          0.0           6.907417E-01   0.0         -8.743030E-03   0.0
          186      G      0.0          0.0           7.082278E-01   0.0         -8.743030E-03   0.0
          187      G      0.0          0.0           7.257138E-01   0.0         -8.743030E-03   0.0
          188      G      0.0          0.0           7.431999E-01   0.0         -8.743030E-03   0.0
          189      G      0.0          0.0           7.606859E-01   0.0         -8.743030E-03   0.0
          190      G      0.0          0.0           7.781720E-01   0.0         -8.743030E-03   0.0
          191      G      0.0          0.0           5.334185E-01   0.0         -8.743030E-03   0.0
          192      G      0.0          0.0           5.509045E-01   0.0         -8.743030E-03   0.0
          193      G      0.0          0.0           5.683906E-01   0.0         -8.743030E-03   0.0
          194      G      0.0          0.0           5.858766E-01   0.0         -8.743030E-03   0.0
          195      G      0.0          0.0           6.033627E-01   0.0         -8.743030E-03   0.0
          196      G      0.0          0.0           6.208488E-01   0.0         -8.743030E-03   0.0
          197      G      0.0          0.0           6.383348E-01   0.0         -8.743030E-03   0.0
          198      G      0.0          0.0           6.558209E-01   0.0         -8.743030E-03   0.0
          199      G      0.0          0.0           6.733069E-01   0.0         -8.743030E-03   0.0
          200      G      0.0          0.0           6.907930E-01   0.0         -8.743030E-03   0.0
          201      G      0.0          0.0           7.082790E-01   0.0         -8.743030E-03   0.0
          202      G      0.0          0.0           7.257651E-01   0.0         -8.743030E-03   0.0
          203      G      0.0          0.0           7.432512E-01   0.0         -8.743030E-03   0.0
          204      G      0.0          0.0           7.607372E-01   0.0         -8.743030E-03   0.0
          205      G      0.0          0.0           7.782233E-01   0.0         -8.743030E-03   0.0
          206      G      0.0          0.0           5.334689E-01   0.0         -8.743030E-03   0.0
          207      G      0.0          0.0           5.509550E-01   0.0         -8.743030E-03   0.0
          208      G      0.0          0.0           5.684411E-01   0.0         -8.743030E-03   0.0
          209      G      0.0          0.0           5.859271E-01   0.0         -8.743030E-03   0.0
          210      G      0.0          0.0           6.034132E-01   0.0         -8.743030E-03   0.0
          211      G      0.0          0.0           6.208992E-01   0.0         -8.743030E-03   0.0
          212      G      0.0          0.0           6.383853E-01   0.0         -8.743030E-03   0.0
          213      G      0.0          0.0           6.558714E-01   0.0         -8.743030E-03   0.0
          214      G      0.0          0.0           6.733574E-01   0.0         -8.743030E-03   0.0
          215      G      0.0          0.0           6.908435E-01   0.0         -8.743030E-03   0.0
          216      G      0.0          0.0           7.083295E-01   0.0         -8.743030E-03   0.0
          217      G      0.0          0.0           7.258156E-01   0.0         -8.743030E-03   0.0
          218      G      0.0          0.0           7.433017E-01   0.0         -8.743030E-03   0.0
          219      G      0.0          0.0           7.607877E-01   0.0         -8.743030E-03   0.0
```

Listing 8-44 Output for Aeroservoelastic Stability Analysis of a Missile (Continued)

```
220      G      0.0           0.0           7.782738E-01   0.0           -8.743030E-03   0.0
          221      G      0.0           0.0           5.335189E-01   0.0           -8.743030E-03   0.0
          222      G      0.0           0.0           5.510049E-01   0.0           -8.743030E-03   0.0
          223      G      0.0           0.0           5.684910E-01   0.0           -8.743030E-03   0.0
          224      G      0.0           0.0           5.859770E-01   0.0           -8.743030E-03   0.0
          225      G      0.0           0.0           6.034631E-01   0.0           -8.743030E-03   0.0
          226      G      0.0           0.0           6.209492E-01   0.0           -8.743030E-03   0.0
          227      G      0.0           0.0           6.384352E-01   0.0           -8.743030E-03   0.0
          228      G      0.0           0.0           6.559213E-01   0.0           -8.743030E-03   0.0
          229      G      0.0           0.0           6.734073E-01   0.0           -8.743030E-03   0.0
          230      G      0.0           0.0           6.908934E-01   0.0           -8.743030E-03   0.0
          231      G      0.0           0.0           7.083795E-01   0.0           -8.743030E-03   0.0
          232      G      0.0           0.0           7.258655E-01   0.0           -8.743030E-03   0.0
          233      G      0.0           0.0           7.433516E-01   0.0           -8.743030E-03   0.0
          234      G      0.0           0.0           7.608376E-01   0.0           -8.743030E-03   0.0
          235      G      0.0           0.0           7.783237E-01   0.0           -8.743030E-03   0.0
          236      G      0.0           0.0           5.335684E-01   0.0           -8.743030E-03   0.0
          237      G      0.0           0.0           5.510545E-01   0.0           -8.743030E-03   0.0
          238      G      0.0           0.0           5.685406E-01   0.0           -8.743030E-03   0.0
          239      G      0.0           0.0           5.860266E-01   0.0           -8.743030E-03   0.0
          240      G      0.0           0.0           6.035127E-01   0.0           -8.743030E-03   0.0
          241      G      0.0           0.0           6.209987E-01   0.0           -8.743030E-03   0.0
          242      G      0.0           0.0           6.384848E-01   0.0           -8.743030E-03   0.0
          243      G      0.0           0.0           6.559709E-01   0.0           -8.743030E-03   0.0
          244      G      0.0           0.0           6.734569E-01   0.0           -8.743030E-03   0.0
          245      G      0.0           0.0           6.909430E-01   0.0           -8.743030E-03   0.0
          246      G      0.0           0.0           7.084290E-01   0.0           -8.743030E-03   0.0
          247      G      0.0           0.0           7.259151E-01   0.0           -8.743030E-03   0.0
          248      G      0.0           0.0           7.434011E-01   0.0           -8.743030E-03   0.0
          249      G      0.0           0.0           7.608872E-01   0.0           -8.743030E-03   0.0
          250      G      0.0           0.0           7.783733E-01   0.0           -8.743030E-03   0.0
         1500      G      0.0           0.0           1.000000E+00   0.0            3.957338E-02   0.0
         1501      G      0.0           0.0           4.148083E-01   0.0            3.789159E-02   0.0
         1502      G      0.0           0.0          -3.409625E-01   0.0            2.754156E-02   0.0
         1503      G      0.0           0.0          -7.864330E-01   0.0            5.061176E-04   0.0
         1504      G      0.0           0.0          -3.692510E-01   0.0           -2.672313E-02   0.0
         1505      G      0.0           0.0           6.554377E-01   0.0           -3.854272E-02   0.0

A ZERO FREQUENCY ROOT HAS EMERGED.  WHEN THE MACH NO., DENSITY AND VELOCITY ARE COMPATIBLE
IT MAY BE INTERPRETED TWO WAYS DEPENDING ON THE SIGN OF THE REAL PART:
  1. (-) A MODE IS CRITICALLY DAMPED, OR,
  2. (+) THE SYSTEM IS DIVERGING.
ONLY THE MOST CRITICAL ( I.E., MOST POSITIVE REAL ROOTS )  ARE PRINTED IN THE FLUTTER SUMMARY.
FOR INFORMATIONAL PURPOSES, THE REMAINING REAL ROOTS ARE PRINTED HERE.

     LESS CRITICAL REAL ROOTS FOR LOOP    1      MACH         VELOCITY         DENSITY
                                             8.00000E-01    6.00000E+03    1.00000E+00

        KFREQ          DAMPING                  COMPLEX EIGENVALUE

       0.0000     -3.1845223E+00       -4.4146395E+02        0.0000000E+00
       0.0000     -3.3902903E-01       -4.6998917E+01        0.0000000E+00


                                                 EIGENVECTOR FROM THE    PK METHOD
  EIGENVALUE =    -9.06309E-03    0.00000E+00       VELOCITY =     6.00000E+03

  EIGENVECTOR
                   1.00000E+00    0.00000E+00
                   8.22280E-01    0.00000E+00
                   4.07178E-01    0.00000E+00
                  -6.44973E-10    0.00000E+00
                   5.29592E-11    0.00000E+00
                   1.88949E-11    0.00000E+00
                   1.04639E-09    0.00000E+00
                   1.04620E-09    0.00000E+00
                   1.04639E-09    0.00000E+00
                  -1.89677E-13    0.00000E+00
                   1.04620E-09    0.00000E+00

                                                 EIGENVECTOR FROM THE    PK METHOD
  EIGENVALUE =     9.06263E-03    0.00000E+00       VELOCITY =     6.00000E+03

  EIGENVECTOR
                   1.00000E+00    0.00000E+00
                   8.22505E-01    0.00000E+00
                   4.07204E-01    0.00000E+00
                  -6.44075E-10    0.00000E+00
                   5.30592E-11    0.00000E+00
                   1.89333E-11    0.00000E+00
                   1.04598E-09    0.00000E+00
                   1.04617E-09    0.00000E+00
                   1.04598E-09    0.00000E+00
                   1.89581E-13    0.00000E+00
                   1.04617E-09    0.00000E+00
```

Listing 8-44 Output for Aeroservoelastic Stability Analysis of a Missile (Continued)

```
                                             EIGENVECTOR FROM THE    PK METHOD
   EIGENVALUE =    -5.88757E+00    5.97599E+00       VELOCITY =     6.00000E+03

   EIGENVECTOR
                    1.00000E+00    0.00000E+00
                    9.76179E-02   -1.29976E-01
                    4.02956E-01   -9.11412E-02
                   -7.69461E-05   -1.32456E-04
                   -1.47581E-05   -1.97261E-05
                   -1.46026E-06   -1.02726E-05
                    5.22787E-03   -5.06462E-03
                    5.20329E-03   -3.85802E-03
                    5.22803E-03   -5.06469E-03
                   -2.47456E-05    1.20670E-03
                    5.20315E-03   -3.85797E-03

0                                                     FLUTTER  SUMMARY
                     CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
     POINT =    1     MACH NUMBER =  0.8000     DENSITY RATIO =  1.0000E+00     METHOD = PK


     KFREQ          1./KFREQ         VELOCITY          DAMPING         FREQUENCY           COMPLEX   EIGENVALUE
      0.0000      1.0000000E+25     5.0000000E+02    -6.5377046E-05     0.0000000E+00    -9.0630892E-03     0.0000000E+00
      0.0000      1.0000000E+25     6.0000000E+02    -6.4318288E-05     0.0000000E+00    -1.0699579E-02     0.0000000E+00
      0.0000      1.0000000E+25     7.0000000E+02    -6.4762105E-05     0.0000000E+00    -1.2568978E-02     0.0000000E+00
      0.0000      1.0000000E+25     8.0000000E+02    -6.4544991E-05     0.0000000E+00    -1.4316389E-02     0.0000000E+00
      0.0000      1.0000000E+25     9.0000000E+02    -6.4327542E-05     0.0000000E+00    -1.6051677E-02     0.0000000E+00
      0.0000      1.0000000E+25     1.0000000E+03    -6.4112925E-05     0.0000000E+00    -1.7775693E-02     0.0000000E+00
0                                                     FLUTTER  SUMMARY
                     CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
     POINT =    2     MACH NUMBER =  0.8000     DENSITY RATIO =  1.0000E+00     METHOD = PK


     KFREQ          1./KFREQ         VELOCITY          DAMPING         FREQUENCY           COMPLEX   EIGENVALUE
      0.0000      1.0000000E+25     5.0000000E+02     6.5373757E-05     0.0000000E+00     9.0626332E-03     0.0000000E+00
      0.0000      1.0000000E+25     6.0000000E+02     6.4323643E-05     0.0000000E+00     1.0700470E-02     0.0000000E+00
      0.0000      1.0000000E+25     7.0000000E+02     6.4763756E-05     0.0000000E+00     1.2569298E-02     0.0000000E+00
      0.0000      1.0000000E+25     8.0000000E+02     6.4547203E-05     0.0000000E+00     1.4316879E-02     0.0000000E+00
      0.0000      1.0000000E+25     9.0000000E+02     6.4330677E-05     0.0000000E+00     1.6052460E-02     0.0000000E+00
      0.0000      1.0000000E+25     1.0000000E+03     6.4117223E-05     0.0000000E+00     1.7776885E-02     0.0000000E+00
0                                                     FLUTTER  SUMMARY
                     CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
     POINT =    3     MACH NUMBER =  0.8000     DENSITY RATIO =  1.0000E+00     METHOD = PK


     KFREQ          1./KFREQ         VELOCITY          DAMPING         FREQUENCY           COMPLEX   EIGENVALUE
      0.0149      6.6934510E+01     5.0000000E+02    -1.9704088E+00     9.5110844E-01    -5.8875723E+00     5.9759906E+00
      0.0117      8.5398402E+01     6.0000000E+02    -3.3676744E+00     8.9456442E-01    -9.4643674E+00     5.6207140E+00
      0.0188      5.3059296E+01     7.0000000E+02    -4.6153551E+00     1.6797578E+00    -2.4355759E+01     1.0554230E+01
      0.0345      2.8998953E+01     8.0000000E+02    -2.2445538E+00     3.5125117E+00    -2.4768384E+01     2.2069762E+01
      0.0415      2.4099470E+01     9.0000000E+02    -1.6429742E+00     4.7549410E+00    -2.4542893E+01     2.9876175E+01
      0.0457      2.1872384E+01     1.0000000E+03    -1.3154099E+00     5.8212197E+00    -2.4056086E+01     3.6575802E+01
0                                                     FLUTTER  SUMMARY
                     CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
     POINT =    4     MACH NUMBER =  0.8000     DENSITY RATIO =  1.0000E+00     METHOD = PK


     KFREQ          1./KFREQ         VELOCITY          DAMPING         FREQUENCY           COMPLEX   EIGENVALUE
      0.6734      1.4850436E+00     5.0000000E+02    -1.9751264E+00     4.2868760E+01    -2.6600248E+02     2.6935236E+02
      0.5618      1.7798620E+00     6.0000000E+02    -1.9701814E+00     4.2921514E+01    -2.6566302E+02     2.6968382E+02
      0.4821      2.0741442E+00     7.0000000E+02    -1.9667461E+00     4.2970383E+01    -2.6550175E+02     2.6999088E+02
      0.4223      2.3678151E+00     8.0000000E+02    -1.9644938E+00     4.3018209E+01    -2.6549286E+02     2.7029138E+02
      0.3758      2.6606601E+00     9.0000000E+02    -1.9629396E+00     4.3068846E+01    -2.6559509E+02     2.7060954E+02
      0.3387      2.9524908E+00     1.0000000E+03    -1.9618198E+00     4.3124251E+01    -2.6578504E+02     2.7095766E+02
0                                                     FLUTTER  SUMMARY
                     CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
     POINT =    5     MACH NUMBER =  0.8000     DENSITY RATIO =  1.0000E+00     METHOD = PK


     KFREQ          1./KFREQ         VELOCITY          DAMPING         FREQUENCY           COMPLEX   EIGENVALUE
      0.7058      1.4169153E+00     5.0000000E+02    -3.8469709E-02     4.4929982E+01    -5.4300650E+00     2.8230341E+02
      0.5873      1.7026081E+00     6.0000000E+02    -4.0494651E-02     4.4869029E+01    -5.7081346E+00     2.8192042E+02
      0.5028      1.9887155E+00     7.0000000E+02    -4.2431441E-02     4.4816249E+01    -5.9741093E+00     2.8158880E+02
      0.4395      2.2752350E+00     8.0000000E+02    -4.4418141E-02     4.4768634E+01    -6.2471811E+00     2.8128962E+02
      0.3903      2.5622051E+00     9.0000000E+02    -4.6537960E-02     4.4723804E+01    -6.5387684E+00     2.8100795E+02
      0.3509      2.8496543E+00     1.0000000E+03    -4.8830887E-02     4.4680492E+01    -6.8542893E+00     2.8073581E+02
0                                                     FLUTTER  SUMMARY
                     CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
```

Listing 8-44 Output for Aeroservoelastic Stability Analysis of a Missile (Continued)

```
 POINT =    6     MACH NUMBER =  0.8000     DENSITY RATIO =  1.0000E+00     METHOD = PK


      KFREQ          1./KFREQ        VELOCITY          DAMPING         FREQUENCY           COMPLEX   EIGENVALUE
       1.9844      5.0393486E-01   5.0000000E+02   -5.1738421E-02   1.2632978E+02   -2.0533773E+01     7.9375339E+02
       1.6529      6.0499520E-01   6.0000000E+02   -5.1661649E-02   1.2627269E+02   -2.0494040E+01     7.9339472E+02
       1.4161      7.0614980E-01   7.0000000E+02   -5.2128520E-02   1.2621510E+02   -2.0669815E+01     7.9303287E+02
       1.2386      8.0738607E-01   8.0000000E+02   -5.2975617E-02   1.2615918E+02   -2.0996396E+01     7.9268150E+02
       1.1005      9.0869180E-01   9.0000000E+02   -5.4098029E-02   1.2610608E+02   -2.1432229E+01     7.9234785E+02
       0.9900      1.0100550E+00   1.0000000E+03   -5.5426299E-02   1.2605645E+02   -2.1949813E+01     7.9203605E+02
0                                                  FLUTTER  SUMMARY
                    CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
      POINT =    7     MACH NUMBER =  0.8000     DENSITY RATIO =  1.0000E+00     METHOD = PK


      KFREQ          1./KFREQ        VELOCITY          DAMPING         FREQUENCY           COMPLEX   EIGENVALUE
       3.9230      2.5490674E-01   5.0000000E+02   -8.4696092E-02   2.4974615E+02   -6.6452612E+01     1.5692014E+03
       3.2690      3.0590247E-01   6.0000000E+02   -8.3397545E-02   2.4973441E+02   -6.5430694E+01     1.5691276E+03
       2.8016      3.5693528E-01   7.0000000E+02   -8.2358787E-02   2.4970008E+02   -6.4606840E+01     1.5689119E+03
       2.4509      4.0800587E-01   8.0000000E+02   -8.1597531E-02   2.4965122E+02   -6.3997144E+01     1.5686049E+03
       2.1781      4.5911430E-01   9.0000000E+02   -8.1078020E-02   2.4959266E+02   -6.3574772E+01     1.5682369E+03
       1.9598      5.1026037E-01   1.0000000E+03   -8.0758258E-02   2.4952742E+02   -6.3307490E+01     1.5678270E+03
0                                                  FLUTTER  SUMMARY
                    CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
      POINT =    8     MACH NUMBER =  0.8000     DENSITY RATIO =  1.0000E+00     METHOD = PK


      KFREQ          1./KFREQ        VELOCITY          DAMPING         FREQUENCY           COMPLEX   EIGENVALUE
      25.5828      3.9088799E-02   5.0000000E+02    4.2941162E-02   1.6286501E+03     2.1971083E+02     1.0233110E+04
      21.3129      4.6920048E-02   6.0000000E+02    4.0015034E-02   1.6281819E+03     2.0468027E+02     1.0230168E+04
      18.2631      5.4755297E-02   7.0000000E+02    3.7086739E-02   1.6277287E+03     1.8964899E+02     1.0227321E+04
      15.9759      6.2594330E-02   8.0000000E+02    3.4155967E-02   1.6272906E+03     1.7461501E+02     1.0224568E+04
      14.1971      7.0436930E-02   9.0000000E+02    3.1222574E-02   1.6268676E+03     1.5957718E+02     1.0221911E+04
      12.7742      7.8282878E-02   1.0000000E+03    2.8286494E-02   1.6264598E+03     1.4453477E+02     1.0219348E+04
     COMPLEX EIGENVALUE = -5.887572E+00,  5.975991E+00
                                          C O M P L E X   E I G E N V E C T O R   NO.        3
                                                           (REAL/IMAGINARY)

     POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
0           1      G      0.0            0.0           -1.369906E-01   0.0           -5.723398E-03   0.0
                          0.0            0.0           -1.299538E-01   0.0           -1.026859E-03   0.0
0           2      G      0.0            0.0           -5.114092E-02   0.0           -5.723134E-03   0.0
                          0.0            0.0           -1.145512E-01   0.0           -1.026803E-03   0.0
0           3      G      0.0            0.0            3.470045E-02   0.0           -5.722269E-03   0.0
                          0.0            0.0           -9.915219E-02   0.0           -1.026241E-03   0.0
0           4      G      0.0            0.0            1.205244E-01   0.0           -5.720845E-03   0.0
                          0.0            0.0           -8.376978E-02   0.0           -1.024506E-03   0.0
0           5      G      8.554962E-20   0.0            2.063249E-01   0.0           -5.719233E-03   0.0
                          7.248459E-21   0.0           -6.842266E-02   0.0           -1.021642E-03   0.0
0           6      G      2.566484E-19   0.0            2.921029E-01   0.0           -5.717938E-03   0.0
                          2.174540E-20   0.0           -5.312070E-02   0.0           -1.018744E-03   0.0
0           7      G      4.277472E-19   0.0            3.778663E-01   0.0           -5.717302E-03   0.0
                          3.624236E-20   0.0           -3.785373E-02   0.0           -1.017167E-03   0.0
0           8      G      5.988471E-19   0.0            4.636251E-01   0.0           -5.717289E-03   0.0
                          5.073941E-20   0.0           -2.259713E-02   0.0           -1.017300E-03   0.0
0           9      G      7.699456E-19   0.0            5.493863E-01   0.0           -5.717535E-03   0.0
                          6.523653E-20   0.0           -7.330759E-03   0.0           -1.018226E-03   0.0
0          10      G      8.554932E-19   0.0            6.351506E-01   0.0           -5.717664E-03   0.0
                          7.248528E-20   0.0            7.947416E-03   0.0           -1.018705E-03   0.0
0          11      G      8.554921E-19   0.0            5.922682E-01   0.0           -5.717631E-03   0.0
                          7.248522E-20   0.0            3.074297E-04   0.0           -1.018585E-03   0.0
0          12      G      8.554921E-19   0.0            5.922682E-01   0.0           -5.717631E-03   0.0
                          7.248522E-20   0.0            3.074297E-04   0.0           -1.018585E-03   0.0
0          21      G      1.215905E-18   0.0            5.849140E-01  -4.223948E-10  -4.902772E-04   0.0
                          1.102609E-19   0.0           -9.096852E-02  -1.666111E-09  -6.085063E-03   0.0
0          22      G      1.236910E-18   1.702522E-19   5.849140E-01  -2.583345E-10  -4.902773E-04   0.0
                          1.064650E-19   1.362523E-20  -9.096853E-02  -1.020175E-09  -6.085064E-03   0.0
0          23      G      1.408500E-18   1.892603E-19   5.849140E-01  -3.866891E-10  -4.902772E-04   0.0
                          1.197656E-19  -1.841813E-20  -9.096854E-02  -1.526057E-09  -6.085063E-03   0.0
0          24      G      8.554921E-19   0.0            5.922682E-01   0.0           -4.902772E-04   0.0
                          7.248522E-20   0.0            3.074297E-04   0.0           -6.085063E-03   0.0
0          25      G      1.298788E-18   7.564116E-20   5.922682E-01  -4.582616E-10  -4.902772E-04   0.0
                          1.341662E-19  -1.500123E-20   3.074199E-04  -1.806738E-09  -6.085063E-03   0.0
0          26      G      1.525942E-18   7.565174E-20   5.922682E-01  -3.629781E-10  -4.902772E-04   0.0
                          9.132477E-20   4.245573E-20   3.074035E-04  -1.432354E-09  -6.085063E-03   0.0
0          27      G      1.268173E-18   0.0            5.996223E-01  -4.225090E-10  -4.902772E-04   0.0
                          1.097967E-19   0.0            9.158337E-02  -1.666217E-09  -6.085063E-03   0.0
0          28      G      1.368258E-18  -3.668022E-19   5.996223E-01  -2.584493E-10  -4.902770E-04   0.0
                          7.661512E-20   1.585872E-20   9.158336E-02  -1.020283E-09  -6.085063E-03   0.0
0          29      G      1.871612E-18  -4.693899E-19   5.996223E-01  -3.868047E-10  -4.902771E-04   0.0
                          9.173667E-20   2.679121E-20   9.158335E-02  -1.526166E-09  -6.085063E-03   0.0
0          45      G      0.0            0.0            1.634276E-01   0.0           -5.720031E-03   0.0
                          0.0            0.0           -7.609085E-02   0.0           -1.023175E-03   0.0
0          49      S      5.227354E-03
                         -5.066478E-03
     COMPLEX EIGENVALUE = -2.660025E+02,  2.693524E+02
```

Listing 8-44 Output for Aeroservoelastic Stability Analysis of a Missile (Continued)

```
 C O M P L E X   E I G E N V E C T O R   NO.          4
                                                            (REAL/IMAGINARY)

      POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
0           1      G      0.0            0.0            9.311963E-04   0.0            4.453578E-05   0.0
                          0.0            0.0           -4.213291E-04   0.0           -2.008035E-05   0.0
0           2      G      0.0            0.0            2.477756E-04   0.0            4.761258E-05   0.0
                          0.0            0.0           -1.484341E-04   0.0           -1.441830E-05   0.0
0           3      G      0.0            0.0           -4.990853E-04   0.0            5.107020E-05   0.0
                          0.0            0.0            5.502295E-06   0.0           -7.612719E-06   0.0
0           4      G      0.0            0.0           -1.229587E-03   0.0            4.357911E-05   0.0
                          0.0            0.0            1.711194E-04   0.0           -1.904151E-05   0.0
0           5      G      1.428282E-21   0.0           -1.743334E-03   0.0            2.346308E-05   0.0
                          1.584336E-22   0.0            6.715064E-04   0.0           -4.942207E-05   0.0
0           6      G      4.284837E-21   0.0           -1.948442E-03   0.0            6.339662E-06   0.0
                          4.752976E-22   0.0            1.595163E-03   0.0           -6.807890E-05   0.0
0           7      G      7.141391E-21   0.0           -2.045313E-03   0.0            1.157404E-05   0.0
                          7.921687E-22   0.0            2.480727E-03   0.0           -4.010646E-05   0.0
0           8      G      9.997955E-21   0.0           -2.416049E-03   0.0            4.088558E-05   0.0
                          1.109027E-21   0.0            2.572158E-03   0.0            3.310568E-05   0.0
0           9      G      1.285450E-20   0.0           -3.289010E-03   0.0            7.362318E-05   0.0
                          1.425907E-21   0.0            1.483634E-03   0.0            1.071025E-04   0.0
0          10      G      1.428276E-20   0.0           -4.528434E-03   0.0            8.712001E-05   0.0
                          1.584330E-21   0.0           -4.180206E-04   0.0            1.365829E-04   0.0
0          11      G      1.428274E-20   0.0           -3.883442E-03   0.0            8.375652E-05   0.0
                          1.584317E-21   0.0            5.880039E-04   0.0            1.292441E-04   0.0
0          12      G      1.428274E-20   0.0           -3.883442E-03   0.0            8.375652E-05   0.0
                          1.584317E-21   0.0            5.880039E-04   0.0            1.292441E-04   0.0
0          21      G      2.004112E-20   0.0            9.973379E-01  -5.114707E-08   6.674809E-02   0.0
                          9.632431E-22   0.0           -2.788553E-04  -1.494027E-07  -5.778382E-05   0.0
0          22      G      2.005692E-20   2.478665E-21   9.973375E-01  -3.133895E-08   6.674808E-02   0.0
                          8.372352E-22  -3.351929E-22  -2.801043E-04  -9.153824E-08  -5.783227E-05   0.0
0          23      G      2.294077E-20   2.321935E-21   9.973371E-01  -4.686162E-08   6.674809E-02   0.0
                          1.064986E-21  -3.234640E-23  -2.812659E-04  -1.368820E-07  -5.779215E-05   0.0
0          24      G      1.428274E-20   0.0           -3.883442E-03   0.0            6.674809E-02   0.0
                          1.584317E-21   0.0            5.880039E-04   0.0           -5.778514E-05   0.0
0          25      G      2.170740E-20   6.991549E-22  -3.883743E-03  -5.544914E-08   6.674809E-02   0.0
                          9.640697E-22  -3.439086E-22   5.871251E-04  -1.619721E-07  -5.778515E-05   0.0
0          26      G      2.376183E-20   1.314152E-21  -3.884246E-03  -4.398190E-08   6.674809E-02   0.0
                          6.965243E-22  -1.093256E-21   5.856546E-04  -1.284708E-07  -5.778515E-05   0.0
0          27      G      2.083800E-20   0.0           -1.005105E+00  -5.114426E-08   6.674809E-02   0.0
                          1.958865E-21   0.0            1.454699E-03  -1.493956E-07  -5.778647E-05   0.0
0          28      G      2.203824E-20  -4.048367E-21  -1.005105E+00  -3.133611E-08   6.674811E-02   0.0
                          3.038530E-21   1.272022E-21   1.453450E-03  -9.153114E-08  -5.773802E-05   0.0
0          29      G      2.787863E-20  -4.089308E-21  -1.005106E+00  -4.685875E-08   6.674810E-02   0.0
                         -3.452290E-21   3.864859E-21   1.452289E-03  -1.368748E-07  -5.777815E-05   0.0
0          45      G      0.0            0.0           -1.524178E-03   0.0            3.461416E-05   0.0
                          0.0            0.0            3.643493E-04   0.0           -3.292281E-05   0.0
0          49      S      6.666434E-02
                         -1.870292E-04
```

Aerothermoelastic Stability of a Wing (Examples HA153A and HA145KR)

The field of aerothermoelasticity considers the effects of thermally induced stresses on structural stiffness and their aeroelastic interaction. There are two mechanisms by which structural stiffness is reduced at high temperature: the first is the reduction of structural moduli of elasticity, and the second is the reduction in stiffness from thermally induced compressive stresses (beam-column effects). The former effect is neglected in this example. The latter effect is considered here by determining the stiffness matrix as a function of temperature using the MSC Nastran SOLution 153, Static Structural and/or Steady State Heat Transfer Analysis with Options: Linear or Nonlinear Analysis. With the temperature-dependent stiffness matrix, restarts can be made in the various Aeroelastic Solution Sequences. SOL 145, Aerodynamic Flutter, is selected here, and the variation of flutter speed with temperature is determined. Restarts in SOL 144, Static Aeroelastic Response, and SOL 146, Dynamic Aeroelastic Response, solutions are also discussed.

Interest in supersonic transport aircraft led to an extensive literature related to aerothermoelasticity in the late 1950s, some examples of which include Budiansky and Mayers (1956) [Reference 10], Bisplinghoff (1956) [Reference 7], Turner, Dill, Martin, and Melosh (1960) [Reference 61], and a Proceedings of Symposium on Aerothermoelasticity (Anon., 1961) [Reference 2]. A recent assessment of analysis and testing applicable to the National Aero-Space Plane is presented by Friedman et al. (1988) [Reference 17]and contains additional references.

The example is a small wing that might be typical of a cantilevered wind tunnel model (see Figure 8-22). It has an unswept, rectangular planform with an internal structure that consists of three spars connected only by ribs at the root and at the tip. In order to emphasize thermoelastic effects, the closing ribs are assumed to be rigid, the main (center) spar is not heated, and the forward and aft spars are assumed to be heated uniformly to the same temperature. The spars are assumed to be weightless but support a number of concentrated weights. The following geometry and other model properties are assumed for the input to SOL 153.

The rectangular lifting surface extends forward and aft of the structural model. A wing span of 100.0 in. and a wing chord of 40.0 in. are assumed. The wing spars are spaced 10.0 in apart and are located within the planform such that the wing leading edge is 5.0 in. forward of the front spar and the trailing edge is 15.0 in. behind the rear spar. The spars are thus located at 12.5%, 37.5%, and 62.5% of the wing chord. There are no intermediate ribs connecting the spars between the root and the tip. The three spars are assumed to be uniform across the span and to have the same section properties, each being relatively stiff in the chordwise direction but weak in torsion. The spar material is assumed to be aluminum with moduli $E = 10.3 \times 10^6$ and $G = 3.9 \times 10^6$ psi, and coefficient of thermal expansion $\alpha = 1.244 \times 10^{-5}$ in/in/°F. The spar section properties are assumed to be: area $A = 2.0$ in^2, $I_y = 1.0$ in^4, $I_z = 100.0$ in^4, $I_{yz} = 0.0$, and $J = 0.1$ in^4.

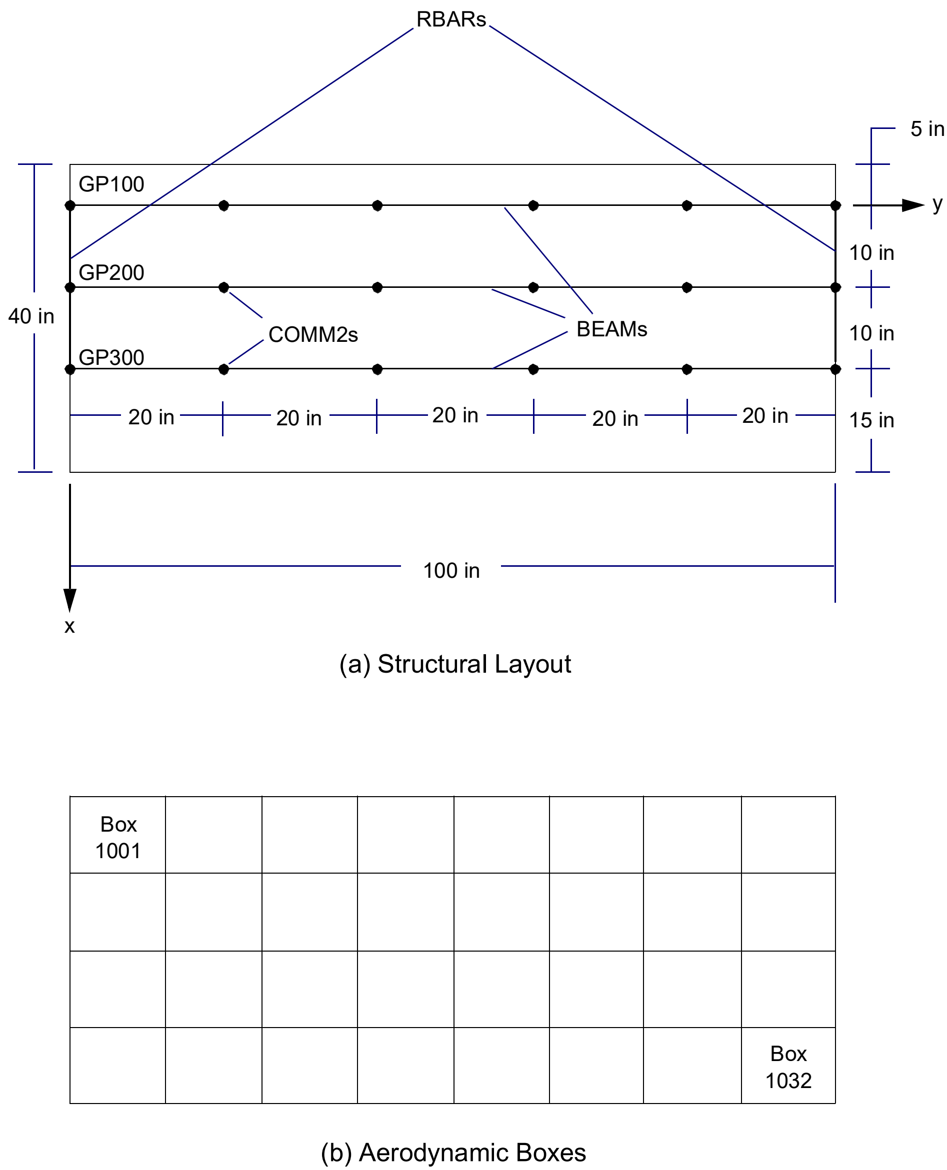

Figure 8-22 Structural and Aerodynamic Models for Aerothermoelastic Example

The MSC Nastran structural model consists of GRIDs, BEAMs (note that SOL 153 does not support the MSC Nastran BAR element), RBARs, and CONM2s. The structural layout and the aerodynamic boxes are shown in Figure 8-22. Each spar is modeled by five equal length BEAM elements. The leading edge spar has GRIDs 100 through 105 and CBEAMs 101 through 105, the main spar has GRIDs 200 through 205 and CBEAMs 201 through 205, and the aft spar has GRIDs 300 through 305 and CBEAMs 301 through 305.

Each spar element has the same properties listed on PBEAM 100 with material properties on MAT1 1. Although no variation of material properties with temperature is considered here, provision is made for variations with temperature by including the MATT1 entry with its associated TABLEMi entries using the same properties at both ends of the tabulated temperature range. Root GRIDs 100 and 200 are rigidly connected by rigid bar RBAR 100, and GRIDs 200 and 300 are connected by RBAR 200. Tip GRIDs 105 and 205 are connected by RBAR 105, and GRIDs 205 and 305 are connected by RBAR 205.

Constraints are an important consideration in this restart analysis since statically determinate constraints are desirable in SOL 153, but the different MSC Nastran aeroelastic SOLs may require different constraints. The flutter analysis of this example assumes a cantilever condition, but a static aeroelastic analysis requires a SUPORT entry, so the specification of the cantilever condition must be completed in the restart flutter analysis. For these reasons, the initial constraints imposed on the structure are only as many as the aeroelastic analyses permit. For symmetric aeroelastic analyses these are DOFs T1, T2, R1, and R3 and are imposed in the permanent constraint field on GRID 200 (1246). The additional cantilever constraints (DOFs T3, and R2, that is, 35) for the flutter analysis will be included in the Bulk Data for the restart in SOL 145 using the database from SOL 153. For the symmetric static aeroelastic analysis, GRID 200 would be SUPORTed in DOFs T3 and R2 in the restart in SOL 144 from the SOL 153 database. The PARAM,WTMASS is included in the Bulk Data for SOL 153 for convenience since it is needed in all of the aeroelastic solutions to convert input weight to mass units. The PARAM,LGDISP,1 is required in SOL 153 to account for large displacement effects in updating element coordinates and follower forces.

The temperature data are input on TEMP and TEMPD entries. The TEMPD entry is used to specify all temperatures not specified on the TEMP entry and is also used here to specify the initial temperature. Four sets of TEMP entries are used to specify the increase in temperature on the forward and aft spars. TEMP 2 specifies a slight temperature increase of 0.001°F to simulate the cold condition. TEMPs 3, 4, and 5 specify temperatures of 50, 150, and 200°F. The nonlinear parameter entry NLPARM specifies data for the nonlinear iteration strategy: NINC is the number of increments to reach the final temperature; KMETHOD is the method for controlling the stiffness updates; KSTEP is the number of iterations between stiffness updates; CONV selects the convergence criteria; and INTOUT provides intermediate output. For this example, the number of increments NINC is chosen depending on the temperature change: one increment to reach 0.001°F, 4 to go from 0.001 to 50°F, 10 to go from 50 to 150°F, and 10 to go from 150 to 200°F. The other parameters are selected as KMETHOD = AUTO (the default), KSTEP = 1, CONV = PW (the default), and INTOUT = YES.

At the end of the Bulk Data is the CORD2R 2 entry. This is the coordinate system for the spline that connects the aerodynamic and structural grids in the aeroelastic solutions. Normally this coordinate system would be contained in the Bulk Data for the aeroelastic solutions but is placed here to avoid the requirement for a DMAP Alter in the aeroelastic solutions that would skip the coordinate system check in the restart.

SOL 153 Case Control Command

The Case Control Section for SOL 153 specifies the title and subtitle, requests printout of both annotated and sorted Bulk Data entries, and prescribes the initial temperature, before specifying the four subcases to increase the temperatures on the front and rear spars by 200°F.

The Executive Control Section for SOL 153 specifies the problem ID MSC, HA153A, five minutes of CPU time, and SOL 153 for the Nonlinear Statics and Heat Transfer solution.

Main Index

SOL 153 Output

The input data are shown in Listing 8-45, the sorted Bulk Data entries are in Listing 8-46, and selected output data follow in Listing 8-47. The results of interest for the restart are discussed as follows.

Because the structure in SOL 153 is not supported in a statically determinate manner, the stiffness matrix is not well conditioned. This is indicated at the beginning of the output by a warning message regarding excessive matrix factor diagonal ratios. This is not a problem in this example because the restarts in the Aeroelastic SOLs will provide sufficient additional supports.

The remaining output shows the results from the nonlinear iteration module. Due to the purely axial loading that results from the temperature increase in this example, the structure behaves as geometrically linear in every load step. Therefore, the solution converges in one iteration step for every temperature increment. Of concern for the restart is, first, the fact of convergence and, then, the LOOPID number for the stiffness matrix that is saved for the restart. Twenty-five loops were executed and 25 stiffness matrices are saved on the database corresponding to various temperatures from 0.001 to 200°F. The flutter analysis is to be demonstrated at 100°F, and this temperature corresponds to Load Factor 0.500 in Subcase 3 with a LOOPID of 10. To obtain the stiffness matrix corresponding to the temperature of 100°F in the restart it is necessary to add the PARAM,NMLOOP and give it the value of the LOOPID for the temperature of interest, in this case, 10.

SOL 145 Bulk Data Entry

The Bulk Data entries for the restart of Example HA145KR (R for Restart) in SOL 145, Aerodynamic Flutter Analysis, are considered next, and are shown in Listing 8-48. PARAM,GRDPNT,100 requests the weight and balance analysis relative to the root of the front spar at GRID 100. SPC1 imposes the additional constraints to achieve the cantilever boundary condition at the root of the main spar, GRID 200: the DOFs T3 and R2 are also constrained. The aerodynamic data begin with the AERO entry that specifies the reference chord as 20.0 in., sea-level density, and symmetric motion. The CAERO1 1001 entry specifies the unswept rectangular aerodynamic model for the subsonic Doublet-Lattice method with eight equal spanwise divisions and four equal chordwise divisions [see Figure 8-22(b)]; the continuation locates the root and tip leading edges at 5.0 in. forward of the forward spar, the 40.0 in. root and tip chords, and the 100.0 in. span. The PAERO1 1000 entry is required even though there is no fuselage. Linear SPLINE2 1001 connects aerodynamic boxes 1001 through 1032 to the normal structural translations (T3) only along the leading and trailing edge spars via the SET1 1100 GRIDs; a rigid chord is thereby effectively imposed even though there is no chordwise stiffening (ribs) except at the root and tip. The spline axis is aligned with the main spar using the coordinate system CORD2R 1. The MKAERO1 entry assumes incompressible flow, $m = 0.0$, and a range of reduced frequencies, k from 0.001 to 1.0.

The flutter analysis is the final consideration. The vibration analysis for the modal flutter analysis is prescribed on the EIGR entry as the MGIV method, requesting four modes and normalizing the eigenvectors on their maximum components. The FLUTTER entry prescribes the PK-method, FLFACT entries for density, Mach number, and velocities, the output for four flutter modes, and a relaxed convergence criterion, $\varepsilon = 0.01$, for the PK-iteration. PARAM,LMODES,4 specifies all four vibration modes to be used in the flutter analysis, and PARAM,VREF,12.0 outputs velocity in ft/s in the Flutter Summary Tables.

The Case Control Section for the restart must include some information from the initial run. After the title, subtitle, and echo commands, the initial temperature must be given again. The PARAM,NMLOOP was mentioned above. It may be included either in the Bulk Data or in the Case Control. It is shown here in Case Control, and its value of 10 corresponds to the stiffness for 100°F. The additional constraints are called via the SPC command. The METHOD command invokes the EIGR entry, and the SVEC command requests vibration mode shapes. The FLUTTER command requests the PK-flutter analysis. The remaining data specify the plotting formats for the V-g and V-f curves. Finally, the BEGIN BULK command concludes the section.

The Executive Control Section begins with the RESTART statement that specifies the database version to be used. Next are the problem identification, estimated CPU time, and SOL 145 for the flutter analysis. CEND is the last statement in the section.

The input to the restart is shown in Listing 8-48; the sorted Bulk Data are in Listing 8-49, and the output from the flutter analysis is shown in Listing 8-50. The plotted V-g and V-f curves are shown in Figure 8-23. The results of special interest are the following.

The weight and balance analysis shows a total wing weight of 250 lbs, with a center of gravity 60.0 in. outboard from the root and 14.0 in. aft of the front spar. The chordwise position of the center of gravity can also be expressed as 47.5% of the wing chord.

The vibration analysis leads to the first four frequencies of 2.815, 5.649, 17.572, and 27.162 Hz. An examination of the eigenvectors indicates that the first mode is bending and the second mode is torsion. The third and fourth modes are difficult to characterize, but the spars appear to be vibrating somewhat independently due to the lack of chordwise stiffening.

The flutter analysis predicts a second mode instability in Point 2 of the Flutter Summary (a typical bending/torsion flutter because of the close bending and torsion frequencies and aft center of gravity) at a velocity of 155 ft/s and frequency of 3.96 Hz. An instability also appears in Point 1 with a zero frequency at a velocity of 270 ft/s; this is the divergence speed. Both instabilities are seen in Figure 8-23.

The above is a demonstration of the restart for flutter analysis with the front and rear spar temperatures raised 100°F. The vibration and flutter characteristics can be determined for other temperature increases by restarting with other values of PARAM,NMLOOP. The following values, from Listing 8-47, of LOOPID = NMLOOP correspond to the temperature increases noted: NMLOOP = 1 for 0.001°F, NMLOOP = 5 for 50°F, NMLOOP = 20 for 150°F, and NMLOOP = 25 for 200°F. The natural frequencies and flutter speeds have been studied up to 150°F and are shown in Figure 8-24 and Figure 8-25. The dramatic effect of temperature is apparent in the rapid decrease in frequencies and flutter speeds with increasing temperatures. Another study (not shown) of vibration frequencies above 150°F suggests thermally induced buckling around 180°F; this characteristic deserves further investigation.

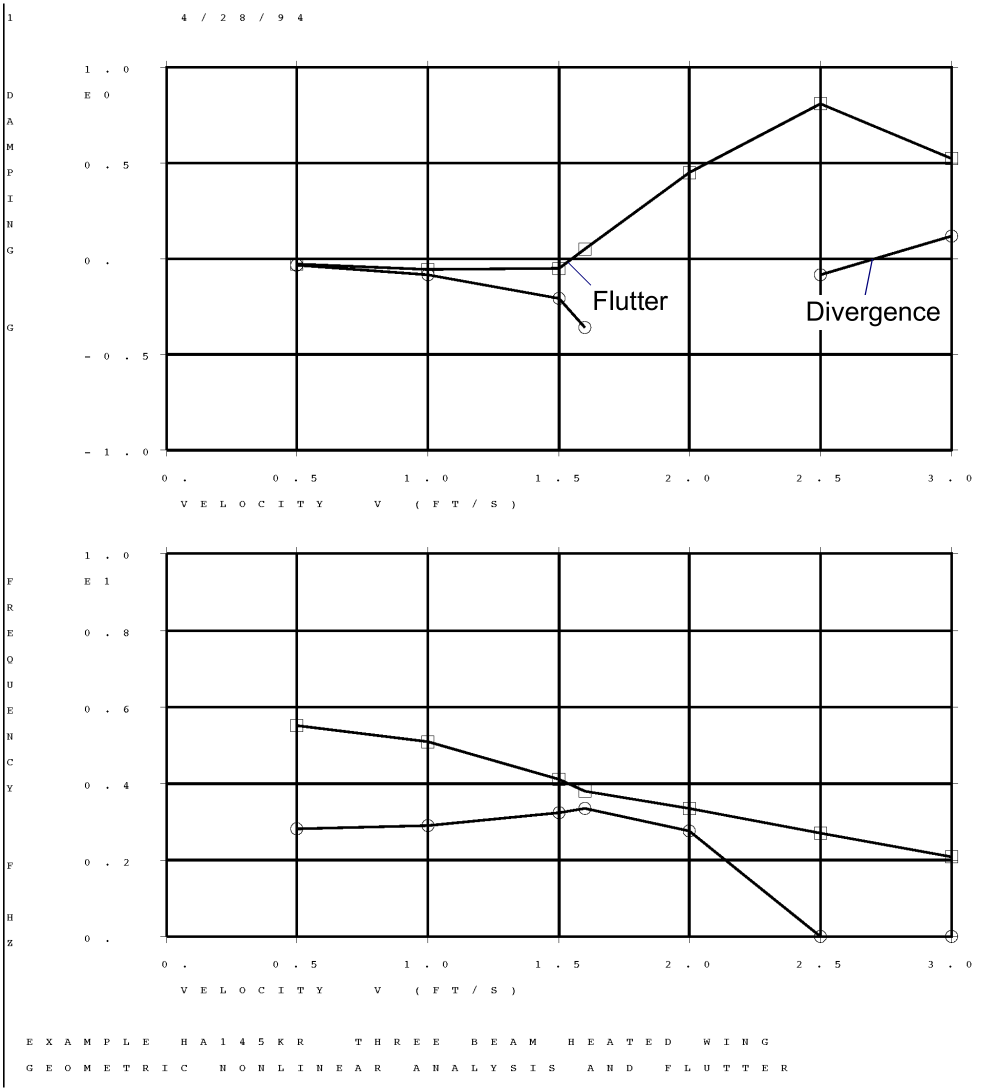

Figure 8-23 V-g and V-f Curves Illustrating Flutter and Divergence Characteristics

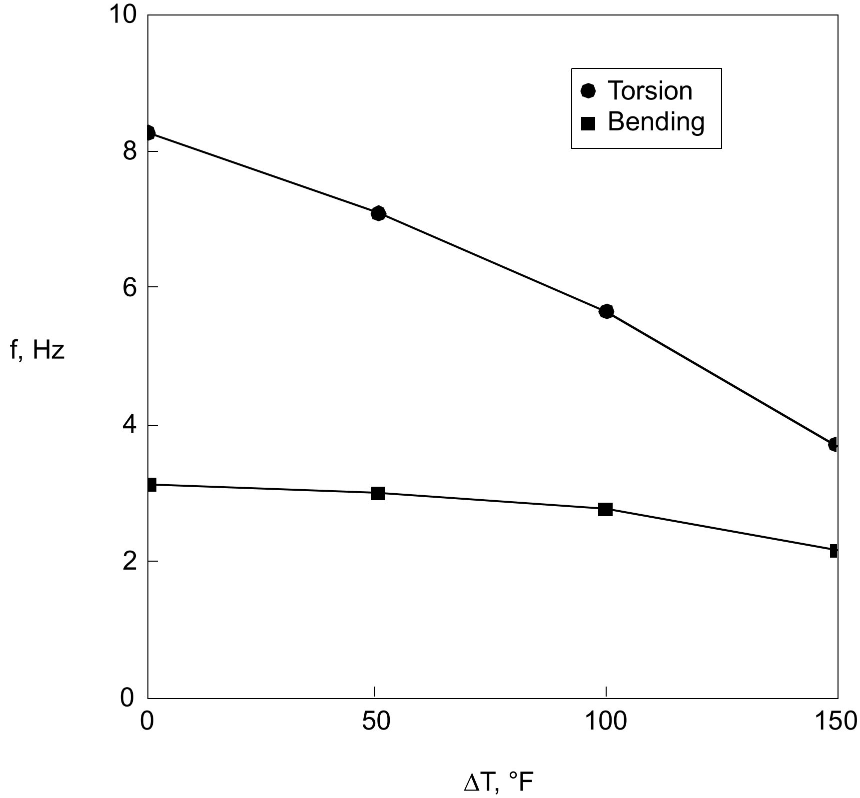

Figure 8-24 Thermoelastic Effect on Cantilever Vibration Frequencies

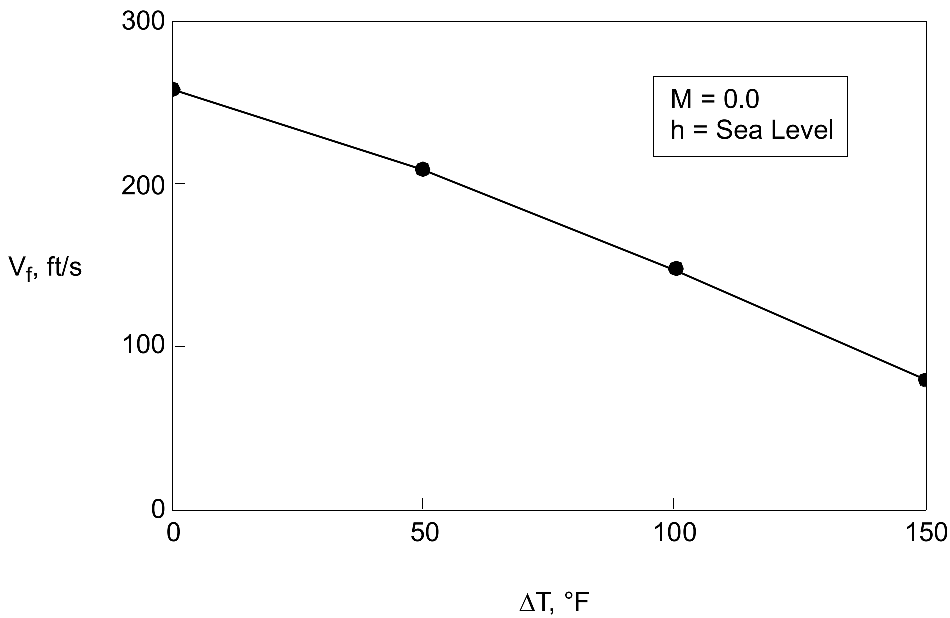

Figure 8-25 Thermoelastic Effect on Flutter Speeds

Restarts in the other aeroelastic SOLs, that is, 144 and 146, can be made in the same way as the SOL 145 restart. Case Control must include the initial temperature TEMP(INIT) set number, and PARAM, NMLOOP must give the LOOPID for the temperature of interest. The Bulk Data must include any additional constraints for the prescribed boundary conditions, and SOL 144 must include the SUPORT entry. Any problems with the conditioning of the stiffness matrix from SOL 153 when restarting in SOL 144 can be overcome by including PARAM, BAILOUT,-1 in the Bulk Data. If there is any mass added to the system in the restart Bulk Data, for example, an unrestrained fuselage mass, a DMAP Alter is required to skip the mass check in the restart.

This example has used SOL 153 assuming the temperatures are known. If transient temperatures are obtained using SOL 159, the TEMP entries required by SOL 153 can be obtained in a "PCH" file by including the THERM(PRINT, PUNCH), OTIME, and SET commands appropriately in the SOL 159 Case Control Section and the PARAM, CURVPLOT,1 entry in the Bulk Data.

Listing 8-45 Input Data for Example HA153A

```
    N A S T R A N    E X E C U T I V E    C O N T R O L    D E C K    E C H O


ID MSC, HA153A
TIME 5 $ CPU TIME IN MINUTES
SOL 153 $ NLSCSH, NONLINEAR STATICS AND HEAT TRANSFER
CEND
```

Listing 8-45 Input Data for Example HA153A (Continued)

```
EXAMPLE HA153A: THREE BAR HEATED WING                                                              PAGE     3
 GEOMETRIC NONLINEAR ANALYSIS

                                     C A S E    C O N T R O L   D E C K   E C H O
            CARD
            COUNT
             1      TITLE = EXAMPLE HA153A: THREE BAR HEATED WING
             2      SUBTI = GEOMETRIC NONLINEAR STATICS AND HEAT TRANSFER ANALYSIS
             3        ECHO       = BOTH
             4        TEMP(INIT) = 1  $ INITIAL TEMPERATURES
             5      SUBCASE 1
             6        LABEL = TEMPERATURE LOAD
             7        TEMP(LOAD) = 2  $ TEMPERATURE INCREASE TO 0.001 DEG F.
             8        NLPARM = 10
             9      SUBCASE 2
            10        LABEL = TEMPERATURE LOAD
            11        TEMP(LOAD) = 3  $ TEMPERATURE INCREASE TO 50 DEG F.
            12        NLPARM = 20
            13      SUBCASE 3
            14        LABEL = TEMPERATURE LOAD
            15        TEMP(LOAD) = 4  $ TEMPERATURE INCREASE TO 150 DEG F.
            16        NLPARM = 30
            17      SUBCASE 4
            18        LABEL = TEMPERATURE LOAD
            19        TEMP(LOAD) = 5  $  TEMPERATURE INCREASE TO 200 DEG F.
            20        NLPARM = 40
            21      BEGIN BULK
```

Listing 8-45 Input Data for Example HA153A (Continued)

```
EXAMPLE HA153A: THREE BAR HEATED WING                                                                    PAGE     4
 GEOMETRIC NONLINEAR ANALYSIS

                                        I N P U T   B U L K   D A T A   D E C K   E C H O

                            .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                            $
                            $       THE GRID ENTRY DEFINES THE LOCATION OF A GEOMETRIC GRID
                            $       POINT, THE DIRECTIONS OF ITS DISPLACEMENT, AND ITS PERMANENT
                            $       SINGLE-POINT CONSTRAINTS.
                            $
                            $       ID      CP      X1      X2      X3      CD      PS      SEID
                            GRID    100             0.      0.      0.
                            GRID    101             0.      20.     0.
                            GRID    102             0.      40.     0.
                            GRID    103             0.      60.     0.
                            GRID    104             0.      80.     0.
                            GRID    105             0.      100.    0.
                            GRID    200             10.     0.      0.              1246
                            GRID    201             10.     20.     0.
                            GRID    202             10.     40.     0.
                            GRID    203             10.     60.     0.
                            GRID    204             10.     80.     0.
                            GRID    205             10.     100.    0.
                            GRID    300             20.     0.      0.
                            GRID    301             20.     20.     0.
                            GRID    302             20.     40.     0.
                            GRID    303             20.     60.     0.
                            GRID    304             20.     80.     0.
                            GRID    305             20.     100.    0.
                            $                                                                       $
                            $                                                                       $
                            $            * * STRUCTURAL STIFFNESS PROPERTIES * *                    $
                            $
                            $       THE CBEAM ENTRY DEFINES A BEAM ELEMENT.
                            $                                                                       $
                            $       EID     PID     GA      GB      X1      X2      X3
                            CBEAM   101     100     100     101     0.      0.      1.
                            CBEAM   102     100     101     102     0.      0.      1.
                            CBEAM   103     100     102     103     0.      0.      1.
                            CBEAM   104     100     103     104     0.      0.      1.
                            CBEAM   105     100     104     105     0.      0.      1.
                            CBEAM   201     100     200     201     0.      0.      1.
                            CBEAM   202     100     201     202     0.      0.      1.
                            CBEAM   203     100     202     203     0.      0.      1.
                            CBEAM   204     100     203     204     0.      0.      1.
                            CBEAM   205     100     204     205     0.      0.      1.
                            CBEAM   301     100     300     301     0.      0.      1.
                            CBEAM   302     100     301     302     0.      0.      1.
                            CBEAM   303     100     302     303     0.      0.      1.
                            CBEAM   304     100     303     304     0.      0.      1.
                            CBEAM   305     100     304     305     0.      0.      1.
                            $                                                                       $
                            $       THE PBEAM ENTRY DEFINES THE PROPERTIES OF A BEAM ELEMENT.
                            $                                                                       $
                            $       PID     MID     A(A)    I1(A)   I2(A)   I12(A)  J(A)    NSM(A)  +PB1
                            PBEAM   100     1       2.0     1.0     100.    0.0     0.1             +PB100
                            $+PB1   SO      X/XB    A       I1      I2      I12     J       NSM
                            +PB100  NO      1.0                                                     $
                            $
                            $       THE RBAR ENTRY DEFINES A RIGID BAR WITH SIX DEGREES OF
                            $       FREEDOM AT EACH END.
                            $                                                                       $
                            $       EID     GA      GB      CNA     CNB     CMA     CMB
                            RBAR    100     200     100     123456
                            RBAR    105     105     205     123456
                            RBAR    200     200     300     123456
                            RBAR    205     205     305     123456
                            $                                                                       $
                            $       THE MAT1 ENTRY DEFINES THE MATERIAL PROPERTIES FOR LINEAR,      $
                            $       TEMPERATURE-INDEPENDENT, ISOTROPIC MATERIALS.                   $
                            $                                                                       $
                            $       MID     E       G       NU      RHO     A       TREF    GE
                            MAT1    1       10.3+6  3.9+6                   1.244-5 0.0
                            $                                                                       $
```

Listing 8-45 Input Data for Example HA153A (Continued)

```
$       THE MATT1 ENTRY SPECIFIES TEMPERATURE-DEPENDENT PROPERTIES
$       ON MAT1 ENTRY FIELDS VIA  TABLEMI ENTRIES.
$
$       MID     T(E)    T(G)    T(NU)   T(RHO)  T(A)            T(GE)
MATT1   1       1       2                       3
$
TABLEM1 1                                                               +TABM1
+TABM1  0.0     10.3+6  200.0   10.3+6  ENDT
TABLEM1 2                                                               +TABM2
+TABM2  0.0     3.9+6   200.0   3.9+6   ENDT
TABLEM1 3                                                               +TABM3
+TABM3  0.0     1.244-5 200.0   1.244-5 ENDT
$                                                                       $
$                 * * MASS AND INERTIA PROPERTIES * *                   $
$
$       THE CONM2 ENTRY DEFINES A CONCENTRATED MASS AT A GRID POINT.
$                                                                       $
$       EID     G       CID     M       X1      X2      X3
CONM2   101     101     0       5.0
CONM2   102     102     0       5.0
CONM2   103     103     0       5.0
CONM2   104     104     0       5.0
CONM2   105     105     0       5.0
CONM2   201     201     0       20.0
CONM2   202     202     0       20.0
CONM2   203     203     0       20.0
CONM2   204     204     0       20.0
CONM2   205     205     0       20.0
CONM2   301     301     0       25.0
CONM2   302     302     0       25.0
CONM2   303     303     0       25.0
CONM2   304     304     0       25.0
CONM2   305     305     0       25.0
$                                                                       $
$        THE PARAM,WTMASS,GINV CAUSES ALL THE STRUCTURAL MASSES AND     $
$        MASS DENSITIES TO BE MULTIPLIED BY GINV (that is, BY ONE OVER     $
$        THE ACCELERATION OF GRAVITY).  THE DYNAMIC PRESSURE SUPPLIED   $
$        FOR AERODYNAMIC FORCE CALCULATIONS WILL NOT BE MULTIPLIED      $
$        BY GINV.                                                       $
$                                                                       $
PARAM   WTMASS  .0025907
$
$
$       *  *  *  REQUEST GEOMETRIC NONLINEAR EFFECTS  *  *  *
$
$       IF LGDISP = 1, ALL THE NONLINEAR ELEMENT TYPES THAT HAVE A
$       LARGE DISPLACEMENT CAPABILITY WILL BE ASSUMED TO HAVE LARGE
$       DISPLACEMENT EFFECTS, that is, UPDATED ELEMENT COORDINATES
$       AND FOLLOWER FORCES.  IF LGDISP = -1 (DEFAULT), THEN NO LARGE
$       DISPLACEMENT EFFECTS WILL BE CONSIDERED.
$
PARAM   LGDISP  1
$
$               *  *  *  TEMPERATURE DATA  *  *  *
$
$       THE TEMP ENTRY DEFINES THE TEMPERATURE AT GRID POINTS FOR
$       DETERMINATION OF THERMAL LOADING, TEMPERATURE-DEPENDENT
$       MATERIAL PROPERTIES, OR STRESS RECOVERY.  THE TEMPD ENTRY
$       DEFINES A TEMPERATURE VALUE FOR ALL GRID POINTS OF THE
$       STRUCTURAL MODEL WHICH HAVE NOT BEEN GIVEN A TEMPERATURE
$       ON A TEMP ENTRY.
$
TEMPD   1       0.
TEMPD   2       0.
TEMP    2       100     0.001   101     0.001   102     0.001
TEMP    2       103     0.001   104     0.001   105     0.001
TEMP    2       300     0.001   301     0.001   302     0.001
TEMP    2       303     0.001   304     0.001   305     0.001
TEMPD   3       0.
TEMP    3       100     50.     101     50.     102     50.
TEMP    3       103     50.     104     50.     105     50.
TEMP    3       300     50.     301     50.     302     50.
TEMP    3       303     50.     304     50.     305     50.
TEMPD   4       0.
TEMP    4       100     150.    101     150.    102     150.
TEMP    4       103     150.    104     150.    105     150.
TEMP    4       300     150.    301     150.    302     150.
TEMP    4       303     150.    304     150.    305     150.
TEMPD   5       0.
TEMP    5       100     200.    101     200.    102     200.
TEMP    5       103     200.    104     200.    105     200.
TEMP    5       300     200.    301     200.    302     200.
TEMP    5       303     200.    304     200.    305     200.
```

Listing 8-45 Input Data for Example HA153A (Continued)

```
$
$       *  *  *  NONLINEAR SOLUTION PARAMETERS  *  *  *
$
$       THE NLPARM ENTRY DEFINES A SET OF PARAMETERS FOR NONLINEAR
$       STATIC ANALYSIS ITERATION STRATEGY.
$
$       ID      NINC    DT      KMETHOD KSTEP   MAXITER CONV    INTOUT
NLPARM  10      1               AUTO    1               PW      YES
NLPARM  20      4               AUTO    1               PW      YES
NLPARM  30      10              AUTO    1               PW      YES
NLPARM  40      10              AUTO    1               PW      YES
$
$       THE CORD2R ENTRY DEFINES A RECTANGULAR COORDINATE SYSTEM USING
$       THE COORDINATES OF THREE POINTS.
$
$       CID     RID     A1      A2      A3      B1      B2      B3      +CD
CORD2R  1       0       20.     0.      0.      20.     0.      10.     +CRD
$+CD    C1      C2      C3
+CRD    30.     0.      0.
$
ENDDATA
INPUT BULK DATA CARD COUNT =     173
```

Listing 8-46 Sorted Bulk Data for Example HA153A

```
EXAMPLE HA153A: THREE BAR HEATED WING                                                                         PAGE     8
 GEOMETRIC NONLINEAR STATICS AND HEAT TRANSFER ANALYSIS

                                       S O R T E D   B U L K   D A T A   E C H O
            CARD
            COUNT        .  1  ..  2  ..  3  ..  4  ..  5  ..  6  ..  7  ..  8  ..  9  ..  10  .
               1-        CBEAM   101     100     100     101     0.      0.      1.
               2-        CBEAM   102     100     101     102     0.      0.      1.
               3-        CBEAM   103     100     102     103     0.      0.      1.
               4-        CBEAM   104     100     103     104     0.      0.      1.
               5-        CBEAM   105     100     104     105     0.      0.      1.
               6-        CBEAM   201     100     200     201     0.      0.      1.
               7-        CBEAM   202     100     201     202     0.      0.      1.
               8-        CBEAM   203     100     202     203     0.      0.      1.
               9-        CBEAM   204     100     203     204     0.      0.      1.
              10-        CBEAM   205     100     204     205     0.      0.      1.
              11-        CBEAM   301     100     300     301     0.      0.      1.
              12-        CBEAM   302     100     301     302     0.      0.      1.
              13-        CBEAM   303     100     302     303     0.      0.      1.
              14-        CBEAM   304     100     303     304     0.      0.      1.
              15-        CBEAM   305     100     304     305     0.      0.      1.
              16-        CONM2   101     101     0       5.0
              17-        CONM2   102     102     0       5.0
              18-        CONM2   103     103     0       5.0
              19-        CONM2   104     104     0       5.0
              20-        CONM2   105     105     0       5.0
              21-        CONM2   201     201     0       20.0
              22-        CONM2   202     202     0       20.0
              23-        CONM2   203     203     0       20.0
              24-        CONM2   204     204     0       20.0
              25-        CONM2   205     205     0       20.0
              26-        CONM2   301     301     0       25.0
              27-        CONM2   302     302     0       25.0
              28-        CONM2   303     303     0       25.0
              29-        CONM2   304     304     0       25.0
              30-        CONM2   305     305     0       25.0
              31-        CORD2R  1       0       20.     0.      0.      20.     0.      10.     +CRD
              32-        +CRD    30.     0.      0.
              33-        GRID    100             0.      0.      0.
              34-        GRID    101             0.      20.     0.
              35-        GRID    102             0.      40.     0.
              36-        GRID    103             0.      60.     0.
              37-        GRID    104             0.      80.     0.
              38-        GRID    105             0.      100.    0.
              39-        GRID    200             10.     0.      0.              1246
              40-        GRID    201             10.     20.     0.
              41-        GRID    202             10.     40.     0.
              42-        GRID    203             10.     60.     0.
              43-        GRID    204             10.     80.     0.
              44-        GRID    205             10.     100.    0.
              45-        GRID    300             20.     0.      0.
              46-        GRID    301             20.     20.     0.
              47-        GRID    302             20.     40.     0.
              48-        GRID    303             20.     60.     0.
              49-        GRID    304             20.     80.     0.
              50-        GRID    305             20.     100.    0.
```

Listing 8-46 Sorted Bulk Data for Example HA153A (Continued)

```
 51-        MAT1    1       10.3+6  3.9+6                   1.244-5 0.0
 52-        MATT1   1       1       2                       3
 53-        NLPARM  10      1               AUTO    1               PW      YES
 54-        NLPARM  20      4               AUTO    1               PW      YES
 55-        NLPARM  30      10              AUTO    1               PW      YES
 56-        NLPARM  40      10              AUTO    1               PW      YES
 57-        PARAM   LGDISP  1
 58-        PARAM   WTMASS  .0025907
 59-        PBEAM   100     1       2.0     1.0     100.    0.0     0.1             +PB100
 60-        +PB100  NO      1.0                                                     $
 61-        RBAR    100     200     100     123456
 62-        RBAR    105     105     205     123456
 63-        RBAR    200     200     300     123456
 64-        RBAR    205     205     305     123456
 65-        TABLEM1 1                                                               +TABM1
 66-        +TABM1  0.0     10.3+6  200.0   10.3+6  ENDT
 67-        TABLEM1 2                                                               +TABM2
 68-        +TABM2  0.0     3.9+6   200.0   3.9+6   ENDT
 69-        TABLEM1 3                                                               +TABM3
 70-        +TABM3  0.0     1.244-5 200.0   1.244-5 ENDT
 71-        TEMP    2       100     0.001   101     0.001   102     0.001
 72-        TEMP    2       103     0.001   104     0.001   105     0.001
 73-        TEMP    2       300     0.001   301     0.001   302     0.001
 74-        TEMP    2       303     0.001   304     0.001   305     0.001
 75-        TEMP    3       100     50.     101     50.     102     50.
 76-        TEMP    3       103     50.     104     50.     105     50.
 77-        TEMP    3       300     50.     301     50.     302     50.
 78-        TEMP    3       303     50.     304     50.     305     50.
 79-        TEMP    4       100     150.    101     150.    102     150.
 80-        TEMP    4       103     150.    104     150.    105     150.
 81-        TEMP    4       300     150.    301     150.    302     150.
 82-        TEMP    4       303     150.    304     150.    305     150.
 83-        TEMP    5       100     200.    101     200.    102     200.
 84-        TEMP    5       103     200.    104     200.    105     200.
 85-        TEMP    5       300     200.    301     200.    302     200.
 86-        TEMP    5       303     200.    304     200.    305     200.
 87-        TEMPD   1       0.
 88-        TEMPD   2       0.
 89-        TEMPD   3       0.
 90-        TEMPD   4       0.
 91-        TEMPD   5       0.
            ENDDATA
      TOTAL COUNT=        92
```

Listing 8-47 Output for Example HA153A

```
    EXAMPLE HA153A: THREE BAR HEATED WING                                                                     PAGE    11
     GEOMETRIC NONLINEAR STATICS AND HEAT TRANSFER ANALYSIS

*** USER INFORMATION MESSAGE 4158 (DFMSA)
---STATISTICS FOR SPARSE DECOMPOSITION OF DATA BLOCK KLLRH    FOLLOW
          NUMBER OF NEGATIVE TERMS ON FACTOR DIAGONAL =      1
          MAXIMUM RATIO OF MATRIX DIAGONAL TO FACTOR DIAGONAL = 1.2E+17 AT ROW NUMBER    29
*** USER WARNING MESSAGE 4698.  STATISTICS FOR DECOMPOSITION OF MATRIX KLLRH   .
THE FOLLOWING DEGREES OF FREEDOM HAVE FACTOR DIAGONAL RATIOS GREATER THAN
 1.00000E+07 OR HAVE NEGATIVE TERMS ON THE FACTOR DIAGONAL.


        GRID POINT ID       DEGREE OF FREEDOM   MATRIX/FACTOR DIAGONAL RATIO       MATRIX DIAGONAL

            105                  R2                  1.20955E+17                   7.48913E+06
            301                  T3                  2.61442E+16                   2.97225E+04

                             N O N - L I N E A R   I T E R A T I O N   M O D U L E   O U T P U T

    STIFFNESS UPDATE TIME          2.65 SECONDS                                                               SUBCASE        1
           ITERATION TIME          0.34 SECONDS                                                        LOAD FACTOR    1.000

                        - - - CONVERGENCE  FACTORS - - -                      - - - LINE SEARCH DATA - - -
ITERATION      EUI         EPI         EWI      LAMBDA       DLMAG       FACTOR     E-FIRST     E-FINAL   NQNV  NLS  ENIC  NDV  MDV

       1  9.9000E+01  4.1903E-08  4.1903E-08  1.0000E-01  8.8379E-10  1.0000E+00 -1.0525E-09 -1.0525E-09    0    0          0    1
*** USER    INFORMATION MESSAGE 6186,
    *** SOLUTION HAS CONVERGED ***

        SUBID    1     LOOPID    1     LOAD STEP    1.000     LOAD FACTOR    1.00000

^^^ DMAP INFORMATION MESSAGE 9005 (NLSCSH) -    THE SOLUTION FOR LOOPID=           1 IS SAVED FOR RESTART

                             N O N - L I N E A R   I T E R A T I O N   M O D U L E   O U T P U T
    STIFFNESS UPDATE TIME          2.65 SECONDS                                                               SUBCASE        2
           ITERATION TIME          0.33 SECONDS                                                        LOAD FACTOR    0.250

                        - - - CONVERGENCE  FACTORS - - -                      - - - LINE SEARCH DATA - - -
ITERATION      EUI         EPI         EWI      LAMBDA       DLMAG       FACTOR     E-FIRST     E-FINAL   NQNV  NLS  ENIC  NDV  MDV

       1  9.8992E+01  3.6350E-12  3.6347E-12  1.0000E-01  8.7635E-10  1.0000E+00  3.6759E-14  3.6759E-14    0    0     0    0    1
*** USER    INFORMATION MESSAGE 6186,
    *** SOLUTION HAS CONVERGED ***

        SUBID    2     LOOPID    2     LOAD STEP    1.250     LOAD FACTOR    0.25000

^^^ DMAP INFORMATION MESSAGE 9005 (NLSCSH) -    THE SOLUTION FOR LOOPID=           2 IS SAVED FOR RESTART

                             N O N - L I N E A R   I T E R A T I O N   M O D U L E   O U T P U T
    STIFFNESS UPDATE TIME          2.65 SECONDS                                                               SUBCASE        2
           ITERATION TIME          0.34 SECONDS                                                        LOAD FACTOR    0.500

                        - - - CONVERGENCE  FACTORS - - -                      - - - LINE SEARCH DATA - - -
ITERATION      EUI         EPI         EWI      LAMBDA       DLMAG       FACTOR     E-FIRST     E-FINAL   NQNV  NLS  ENIC  NDV  MDV

       1  4.9498E+01  6.2422E-13  3.1210E-13  1.0000E-01  2.7370E-10  1.0000E+00  1.1959E-13  1.1959E-13    0    0     0    0    1
*** USER    INFORMATION MESSAGE 6186,
    *** SOLUTION HAS CONVERGED ***

        SUBID    2     LOOPID    3     LOAD STEP    1.500     LOAD FACTOR    0.50000

^^^ DMAP INFORMATION MESSAGE 9005 (NLSCSH) -    THE SOLUTION FOR LOOPID=           3 IS SAVED FOR RESTART

                             N O N - L I N E A R   I T E R A T I O N   M O D U L E   O U T P U T
    STIFFNESS UPDATE TIME          2.65 SECONDS                                                               SUBCASE        2
           ITERATION TIME          0.34 SECONDS                                                        LOAD FACTOR    0.750

                        - - - CONVERGENCE  FACTORS - - -                      - - - LINE SEARCH DATA - - -
ITERATION      EUI         EPI         EWI      LAMBDA       DLMAG       FACTOR     E-FIRST     E-FINAL   NQNV  NLS  ENIC  NDV  MDV

       1  3.2999E+01  3.5641E-12  1.1880E-12  1.0000E-01  1.0808E-09  1.0000E+00 -1.5573E-13 -1.5573E-13    0    0     0    0    1
*** USER    INFORMATION MESSAGE 6186,
    *** SOLUTION HAS CONVERGED ***

        SUBID    2     LOOPID    4     LOAD STEP    1.750     LOAD FACTOR    0.75000
```

Listing 8-47 Output for Example HA153A (Continued)

```
^^^ DMAP INFORMATION MESSAGE 9005 (NLSCSH) -    THE SOLUTION FOR LOOPID=           4 IS SAVED FOR RESTART

                             N O N - L I N E A R   I T E R A T I O N   M O D U L E   O U T P U T

    STIFFNESS UPDATE TIME          2,65 SECONDS                                                             SUBCASE        2
           ITERATION TIME          0.34 SECONDS                                                       LOAD FACTOR    1.000

                       - - - CONVERGENCE  FACTORS - - -                      - - - LINE SEARCH DATA - - -
ITERATION      EUI         EPI         EWI       LAMBDA       DLMAG       FACTOR     E-FIRST     E-FINAL   NQNV  NLS  ENIC  NDV  MDV

       1  2.4750E+01  4.3176E-12  1.0794E-12  1.0000E-01  1.2466E-09  1.0000E+00  1.1400E-13  1.1400E-13    0    0     0    0    1
*** USER    INFORMATION MESSAGE 6186,
    *** SOLUTION HAS CONVERGED ***

        SUBID    2     LOOPID    5     LOAD STEP    2.000     LOAD FACTOR    1.00000

^^^ DMAP INFORMATION MESSAGE 9005 (NLSCSH) -    THE SOLUTION FOR LOOPID=           5 IS SAVED FOR RESTART

                             N O N - L I N E A R   I T E R A T I O N   M O D U L E   O U T P U T

    STIFFNESS UPDATE TIME          2.65 SECONDS                                                             SUBCASE        3
           ITERATION TIME          0.34 SECONDS                                                       LOAD FACTOR    0.100

                       - - - CONVERGENCE  FACTORS - - -                      - - - LINE SEARCH DATA - - -
ITERATION      EUI         EPI         EWI       LAMBDA       DLMAG       FACTOR     E-FIRST     E-FINAL   NQNV  NLS  ENIC  NDV  MDV

       1  1.6500E+01  8.0967E-13  1.3494E-13  1.0000E-01  1.1220E-09  1.0000E+00 -1.2858E-13 -1.2858E-13    0    0     0    0    1
*** USER    INFORMATION MESSAGE 6186,
    *** SOLUTION HAS CONVERGED ***

        SUBID    3     LOOPID    6     LOAD STEP    2.100     LOAD FACTOR    0.10000

^^^ DMAP INFORMATION MESSAGE 9005 (NLSCSH) -    THE SOLUTION FOR LOOPID=           6 IS SAVED FOR RESTART

                             N O N - L I N E A R   I T E R A T I O N   M O D U L E   O U T P U T

    STIFFNESS UPDATE TIME          2.65 SECONDS                                                             SUBCASE        3
           ITERATION TIME          0.34 SECONDS                                                       LOAD FACTOR    0.200

                       - - - CONVERGENCE  FACTORS - - -                      - - - LINE SEARCH DATA - - -
ITERATION      EUI         EPI         EWI       LAMBDA       DLMAG       FACTOR     E-FIRST     E-FINAL   NQNV  NLS  ENIC  NDV  MDV

       1  1.4143E+01  1.0795E-12  1.5422E-13  1.0000E-01  1.4963E-09  1.0000E+00  1.7127E-13  1.7127E-13    0    0     0    0    1
*** USER    INFORMATION MESSAGE 6186,
    *** SOLUTION HAS CONVERGED ***

        SUBID    3     LOOPID    7     LOAD STEP    2.200     LOAD FACTOR    0.20000

^^^ DMAP INFORMATION MESSAGE 9005 (NLSCSH) -    THE SOLUTION FOR LOOPID=           7 IS SAVED FOR RESTART

                             N O N - L I N E A R   I T E R A T I O N   M O D U L E   O U T P U T
    STIFFNESS UPDATE TIME          2.65 SECONDS                                                             SUBCASE        3
           ITERATION TIME          0.36 SECONDS                                                       LOAD FACTOR    0.300

                       - - - CONVERGENCE  FACTORS - - -                      - - - LINE SEARCH DATA - - -
ITERATION      EUI         EPI         EWI       LAMBDA       DLMAG       FACTOR     E-FIRST     E-FINAL   NQNV  NLS  ENIC  NDV  MDV

       1  1.2375E+01  1.0795E-12  1.3493E-13  1.0000E-01  1.4966E-09  1.0000E+00 -1.7143E-13 -1.7143E-13    0    0     0    0    1
*** USER    INFORMATION MESSAGE 6186,
    *** SOLUTION HAS CONVERGED ***

        SUBID    3     LOOPID    8     LOAD STEP    2.300     LOAD FACTOR    0.30000

^^^ DMAP INFORMATION MESSAGE 9005 (NLSCSH) -    THE SOLUTION FOR LOOPID=           8 IS SAVED FOR RESTART

                             N O N - L I N E A R   I T E R A T I O N   M O D U L E   O U T P U T

    STIFFNESS UPDATE TIME          2.65 SECONDS                                                             SUBCASE        3
           ITERATION TIME          0.35 SECONDS                                                       LOAD FACTOR    0.400

                       - - - CONVERGENCE  FACTORS - - -                      - - - LINE SEARCH DATA - - -
ITERATION      EUI         EPI         EWI       LAMBDA       DLMAG       FACTOR     E-FIRST     E-FINAL   NQNV  NLS  ENIC  NDV  MDV

       1  1.1000E+01  8.0966E-13  8.9962E-14  1.0000E-01  1.1225E-09  1.0000E+00  1.2857E-13  1.2857E-13    0    0     0    0    1
*** USER    INFORMATION MESSAGE 6186,
    *** SOLUTION HAS CONVERGED ***

        SUBID    3     LOOPID    9     LOAD STEP    2.400     LOAD FACTOR    0.40000
```

Listing 8-47 Output for Example HA153A (Continued)

```
^^^ DMAP INFORMATION MESSAGE 9005 (NLSCSH) -    THE SOLUTION FOR LOOPID=          9 IS SAVED FOR RESTART

                                   N O N - L I N E A R   I T E R A T I O N   M O D U L E   O U T P U T
    STIFFNESS UPDATE TIME          2.65 SECONDS                                                           SUBCASE        3
           ITERATION TIME          0.35 SECONDS                                                      LOAD FACTOR    0.500

                             - - - CONVERGENCE  FACTORS - - -                     - - - LINE SEARCH DATA - - -
ITERATION      EUI         EPI         EWI       LAMBDA       DLMAG       FACTOR     E-FIRST      E-FINAL   NQNV  NLS  ENIC  NDV  MDV

       1  9.9000E+00  2.2060E-16  2.2060E-17  1.0000E-01  6.5303E-13  1.0000E+00 -5.9890E-16 -5.9890E-16    0    0     0    0    1
*** USER    INFORMATION MESSAGE 6186,
    *** SOLUTION HAS CONVERGED ***

        SUBID    3     LOOPID   10     LOAD STEP    2.500     LOAD FACTOR    0.50000

^^^ DMAP INFORMATION MESSAGE 9005 (NLSCSH) -    THE SOLUTION FOR LOOPID=         10 IS SAVED FOR RESTART

                                   N O N - L I N E A R   I T E R A T I O N   M O D U L E   O U T P U T
    STIFFNESS UPDATE TIME          2.65 SECONDS                                                           SUBCASE        3
           ITERATION TIME          0.35 SECONDS                                                      LOAD FACTOR    0.600

                             - - - CONVERGENCE  FACTORS - - -                     - - - LINE SEARCH DATA - - -
ITERATION      EUI         EPI         EWI       LAMBDA       DLMAG       FACTOR     E-FIRST      E-FINAL   NQNV  NLS  ENIC  NDV  MDV

       1  9.0000E+00  8.0955E-13  7.3596E-14  1.0000E-01  1.1226E-09  1.0000E+00 -1.2896E-13 -1.2896E-13    0    0     0    0    1
*** USER    INFORMATION MESSAGE 6186,
    *** SOLUTION HAS CONVERGED ***

        SUBID    3     LOOPID   11     LOAD STEP    2.600     LOAD FACTOR    0.60000

^^^ DMAP INFORMATION MESSAGE 9005 (NLSCSH) -    THE SOLUTION FOR LOOPID=         11 IS SAVED FOR RESTART

                                   N O N - L I N E A R   I T E R A T I O N   M O D U L E   O U T P U T
    STIFFNESS UPDATE TIME          2.65 SECONDS                                                           SUBCASE        3
           ITERATION TIME          0.35 SECONDS                                                      LOAD FACTOR    0.700

                             - - - CONVERGENCE  FACTORS - - -                     - - - LINE SEARCH DATA - - -
ITERATION      EUI         EPI         EWI       LAMBDA       DLMAG       FACTOR     E-FIRST      E-FINAL   NQNV  NLS  ENIC  NDV  MDV

       1  8.2500E+00  1.0794E-12  8.9947E-14  1.0000E-01  1.4957E-09  1.0000E+00  1.7080E-13  1.7080E-13    0    0     0    0    1
*** USER    INFORMATION MESSAGE 6186,
    *** SOLUTION HAS CONVERGED ***

        SUBID    3     LOOPID   12     LOAD STEP    2.700     LOAD FACTOR    0.70000

^^^ DMAP INFORMATION MESSAGE 9005 (NLSCSH) -    THE SOLUTION FOR LOOPID=         12 IS SAVED FOR RESTART

                                   N O N - L I N E A R   I T E R A T I O N   M O D U L E   O U T P U T

    STIFFNESS UPDATE TIME          2.65 SECONDS                                                           SUBCASE        3
           ITERATION TIME          0.35 SECONDS                                                      LOAD FACTOR    0.800

                             - - - CONVERGENCE  FACTORS - - -                     - - - LINE SEARCH DATA - - -
ITERATION      EUI         EPI         EWI       LAMBDA       DLMAG       FACTOR     E-FIRST      E-FINAL   NQNV  NLS  ENIC  NDV  MDV

       1  7.6154E+00  1.0796E-12  8.3042E-14  1.0000E-01  1.4967E-09  1.0000E+00 -1.7142E-13 -1.7142E-13    0    0     0    0    1
*** USER    INFORMATION MESSAGE 6186,
    *** SOLUTION HAS CONVERGED ***

        SUBID    3     LOOPID   13     LOAD STEP    2.800     LOAD FACTOR    0.80000

^^^ DMAP INFORMATION MESSAGE 9005 (NLSCSH) -    THE SOLUTION FOR LOOPID=         13 IS SAVED FOR RESTART

                                   N O N - L I N E A R   I T E R A T I O N   M O D U L E   O U T P U T
    STIFFNESS UPDATE TIME          2.65 SECONDS                                                           SUBCASE        3
           ITERATION TIME          0.35 SECONDS                                                      LOAD FACTOR    0.900

                             - - - CONVERGENCE  FACTORS - - -                     - - - LINE SEARCH DATA - - -
ITERATION      EUI         EPI         EWI       LAMBDA       DLMAG       FACTOR     E-FIRST      E-FINAL   NQNV  NLS  ENIC  NDV  MDV

       1  7.0714E+00  8.0969E-13  5.7835E-14  1.0000E-01  1.1234E-09  1.0000E+00  1.2811E-13  1.2811E-13    0    0     0    0    1
*** USER    INFORMATION MESSAGE 6186,
    *** SOLUTION HAS CONVERGED ***

        SUBID    3     LOOPID   14     LOAD STEP    2.900     LOAD FACTOR    0.90000

^^^ DMAP INFORMATION MESSAGE 9005 (NLSCSH) -    THE SOLUTION FOR LOOPID=         14 IS SAVED FOR RESTART

                                   N O N - L I N E A R   I T E R A T I O N   M O D U L E   O U T P U T

    STIFFNESS UPDATE TIME          2.65 SECONDS                                                           SUBCASE        3
           ITERATION TIME          0.35 SECONDS                                                      LOAD FACTOR    1.000
```

Listing 8-47 Output for Example HA153A (Continued)

```
                     - - - CONVERGENCE  FACTORS - - -                      - - - LINE SEARCH DATA - - -
ITERATION      EUI         EPI         EWI       LAMBDA       DLMAG       FACTOR     E-FIRST     E-FINAL   NQNV  NLS  ENIC  NDV  MDV

       1  6.6000E+00  1.1978E-16  7.9854E-18  1.0000E-01  1.6295E-12  1.0000E+00 -5.3236E-16 -5.3236E-16    0    0     0    0    1
*** USER    INFORMATION MESSAGE 6186,
    *** SOLUTION HAS CONVERGED ***

        SUBID    3     LOOPID   15     LOAD STEP    3.000     LOAD FACTOR    1.00000

^^^ DMAP INFORMATION MESSAGE 9005 (NLSCSH) -    THE SOLUTION FOR LOOPID=          15 IS SAVED FOR RESTART

                          N O N - L I N E A R   I T E R A T I O N   M O D U L E   O U T P U T

    STIFFNESS UPDATE TIME          2.65 SECONDS                                                             SUBCASE        4
           ITERATION TIME          0.34 SECONDS                                                         LOAD FACTOR    0.100

                     - - - CONVERGENCE  FACTORS - - -                      - - - LINE SEARCH DATA - - -
ITERATION      EUI         EPI         EWI       LAMBDA       DLMAG       FACTOR     E-FIRST     E-FINAL   NQNV  NLS  ENIC  NDV  MDV
       1  3.1935E+00  1.7409E-13  5.6158E-15  1.0000E-01  6.2418E-10  1.0000E+00 -1.4139E-13 -1.4139E-13    0    0     0    0    1
*** USER    INFORMATION MESSAGE 6186,
    *** SOLUTION HAS CONVERGED ***

        SUBID    4     LOOPID   16     LOAD STEP    3.100     LOAD FACTOR    0.10000

^^^ DMAP INFORMATION MESSAGE 9005 (NLSCSH) -    THE SOLUTION FOR LOOPID=          16 IS SAVED FOR RESTART

                          N O N - L I N E A R   I T E R A T I O N   M O D U L E   O U T P U T
    STIFFNESS UPDATE TIME          2.65 SECONDS                                                             SUBCASE        4
           ITERATION TIME          0.34 SECONDS                                                         LOAD FACTOR    0.200
                     - - - CONVERGENCE  FACTORS - - -                      - - - LINE SEARCH DATA - - -
ITERATION      EUI         EPI         EWI       LAMBDA       DLMAG       FACTOR     E-FIRST     E-FINAL   NQNV  NLS  ENIC  NDV  MDV

       1  3.0938E+00  1.7414E-13  5.4419E-15  1.0000E-01  6.2402E-10  1.0000E+00  1.4367E-13  1.4367E-13    0    0     0    0    1
*** USER    INFORMATION MESSAGE 6186,
    *** SOLUTION HAS CONVERGED ***

        SUBID    4     LOOPID   17     LOAD STEP    3.200     LOAD FACTOR    0.20000

^^^ DMAP INFORMATION MESSAGE 9005 (NLSCSH) -    THE SOLUTION FOR LOOPID=          17 IS SAVED FOR RESTART

                          N O N - L I N E A R   I T E R A T I O N   M O D U L E   O U T P U T
    STIFFNESS UPDATE TIME          2.65 SECONDS                                                             SUBCASE        4
           ITERATION TIME          0.34 SECONDS                                                         LOAD FACTOR    0.300
                     - - - CONVERGENCE  FACTORS - - -                      - - - LINE SEARCH DATA - - -
ITERATION      EUI         EPI         EWI       LAMBDA       DLMAG       FACTOR     E-FIRST     E-FINAL   NQNV  NLS  ENIC  NDV  MDV

       1  3.0000E+00  7.5423E-17  2.2855E-18  1.0000E-01  4.0268E-12  1.0000E+00  8.5177E-16  8.5177E-16    0    0     0    0    1
*** USER    INFORMATION MESSAGE 6186,
    *** SOLUTION HAS CONVERGED ***

        SUBID    4     LOOPID   18     LOAD STEP    3.300     LOAD FACTOR    0.30000

^^^ DMAP INFORMATION MESSAGE 9005 (NLSCSH) -    THE SOLUTION FOR LOOPID=          18 IS SAVED FOR RESTART

                          N O N - L I N E A R   I T E R A T I O N   M O D U L E   O U T P U T

    STIFFNESS UPDATE TIME          2.65 SECONDS                                                             SUBCASE        4
           ITERATION TIME          0.34 SECONDS                                                         LOAD FACTOR    0.400

                     - - - CONVERGENCE  FACTORS - - -                      - - - LINE SEARCH DATA - - -
ITERATION      EUI         EPI         EWI       LAMBDA       DLMAG       FACTOR     E-FIRST     E-FINAL   NQNV  NLS  ENIC  NDV  MDV

       1  2.9118E+00  1.7405E-13  5.1190E-15  1.0000E-01  6.2355E-10  1.0000E+00 -1.4214E-13 -1.4214E-13    0    0     0    0    1
*** USER    INFORMATION MESSAGE 6186,
    *** SOLUTION HAS CONVERGED ***

        SUBID    4     LOOPID   19     LOAD STEP    3.400     LOAD FACTOR    0.40000

^^^ DMAP INFORMATION MESSAGE 9005 (NLSCSH) -    THE SOLUTION FOR LOOPID=          19 IS SAVED FOR RESTART

                          N O N - L I N E A R   I T E R A T I O N   M O D U L E   O U T P U T

    STIFFNESS UPDATE TIME          2.65 SECONDS                                                             SUBCASE        4
           ITERATION TIME          0.34 SECONDS                                                         LOAD FACTOR    0.500

                     - - - CONVERGENCE  FACTORS - - -                      - - - LINE SEARCH DATA - - -
ITERATION      EUI         EPI         EWI       LAMBDA       DLMAG       FACTOR     E-FIRST     E-FINAL   NQNV  NLS  ENIC  NDV  MDV

       1  2.8286E+00  1.7418E-13  4.9767E-15  1.0000E-01  6.2483E-10  1.0000E+00  1.4388E-13  1.4388E-13    0    0     0    0    1
*** USER    INFORMATION MESSAGE 6186,
    *** SOLUTION HAS CONVERGED ***

        SUBID    4     LOOPID   20     LOAD STEP    3.500     LOAD FACTOR    0.50000
```

Listing 8-47 Output for Example HA153A (Continued)

```
^^^ DMAP INFORMATION MESSAGE 9005 (NLSCSH) -    THE SOLUTION FOR LOOPID=          20 IS SAVED FOR RESTART

                              N O N - L I N E A R   I T E R A T I O N   M O D U L E   O U T P U T

    STIFFNESS UPDATE TIME          2.65 SECONDS                                                         SUBCASE        4
         ITERATION TIME            0.33 SECONDS                                                    LOAD FACTOR    0.600
                          - - - CONVERGENCE  FACTORS - - -                    - - - LINE SEARCH DATA - - -
ITERATION      EUI         EPI         EWI       LAMBDA       DLMAG       FACTOR     E-FIRST     E-FINAL   NQNV  NLS  ENIC  NDV  MDV

      1  2.7500E+00  8.8191E-14  2.4498E-15  1.0000E-01  1.9606E-10  1.0000E+00  1.1538E-13  1.1538E-13    0    0     0    0    1
*** USER    INFORMATION MESSAGE 6186,
    *** SOLUTION HAS CONVERGED ***

        SUBID    4     LOOPID   21     LOAD STEP    3.600     LOAD FACTOR    0.60000

^^^ DMAP INFORMATION MESSAGE 9005 (NLSCSH) -    THE SOLUTION FOR LOOPID=          21 IS SAVED FOR RESTART

                              N O N - L I N E A R   I T E R A T I O N   M O D U L E   O U T P U T

    STIFFNESS UPDATE TIME          2.65 SECONDS                                                         SUBCASE        4
         ITERATION TIME            0.33 SECONDS                                                    LOAD FACTOR    0.700

                          - - - CONVERGENCE  FACTORS - - -                    - - - LINE SEARCH DATA - - -
ITERATION      EUI         EPI         EWI       LAMBDA       DLMAG       FACTOR     E-FIRST     E-FINAL   NQNV  NLS  ENIC  NDV  MDV

      1  2.6757E+00  1.7420E-13  4.7081E-15  1.0000E-01  6.2424E-10  1.0000E+00 -1.4441E-13 -1.4441E-13    0    0     0    0    1
*** USER    INFORMATION MESSAGE 6186,
    *** SOLUTION HAS CONVERGED ***

        SUBID    4     LOOPID   22     LOAD STEP    3.700     LOAD FACTOR    0.70000

^^^ DMAP INFORMATION MESSAGE 9005 (NLSCSH) -    THE SOLUTION FOR LOOPID=          22 IS SAVED FOR RESTART

                              N O N - L I N E A R   I T E R A T I O N   M O D U L E   O U T P U T

    STIFFNESS UPDATE TIME          2.65 SECONDS                                                         SUBCASE        4
         ITERATION TIME            0.33 SECONDS                                                    LOAD FACTOR    0.800

                          - - - CONVERGENCE  FACTORS - - -                    - - - LINE SEARCH DATA - - -
ITERATION      EUI         EPI         EWI       LAMBDA       DLMAG       FACTOR     E-FIRST     E-FINAL   NQNV  NLS  ENIC  NDV  MDV

      1  2.6053E+00  1.7413E-13  4.5825E-15  1.0000E-01  6.2486E-10  1.0000E+00  1.4285E-13  1.4285E-13    0    0     0    0    1
*** USER    INFORMATION MESSAGE 6186,
    *** SOLUTION HAS CONVERGED ***

        SUBID    4     LOOPID   23     LOAD STEP    3.800     LOAD FACTOR    0.80000

^^^ DMAP INFORMATION MESSAGE 9005 (NLSCSH) -    THE SOLUTION FOR LOOPID=          23 IS SAVED FOR RESTART

                              N O N - L I N E A R   I T E R A T I O N   M O D U L E   O U T P U T

    STIFFNESS UPDATE TIME          2.65 SECONDS                                                         SUBCASE        4
         ITERATION TIME            0.35 SECONDS                                                    LOAD FACTOR    0.900

                          - - - CONVERGENCE  FACTORS - - -                    - - - LINE SEARCH DATA - - -
ITERATION      EUI         EPI         EWI       LAMBDA       DLMAG       FACTOR     E-FIRST     E-FINAL   NQNV  NLS  ENIC  NDV  MDV
      1  2.5385E+00  9.6752E-17  2.4808E-18  1.0000E-01  1.0129E-12  1.0000E+00 -1.4551E-15 -1.4551E-15    0    0     0    0    1
*** USER    INFORMATION MESSAGE 6186,
    *** SOLUTION HAS CONVERGED ***

        SUBID    4     LOOPID   24     LOAD STEP    3.900     LOAD FACTOR    0.90000

^^^ DMAP INFORMATION MESSAGE 9005 (NLSCSH) -    THE SOLUTION FOR LOOPID=          24 IS SAVED FOR RESTART

                              N O N - L I N E A R   I T E R A T I O N   M O D U L E   O U T P U T

    STIFFNESS UPDATE TIME          2.65 SECONDS                                                         SUBCASE        4
         ITERATION TIME            0.32 SECONDS                                                    LOAD FACTOR    1.000

                          - - - CONVERGENCE  FACTORS - - -                    - - - LINE SEARCH DATA - - -
ITERATION      EUI         EPI         EWI       LAMBDA       DLMAG       FACTOR     E-FIRST     E-FINAL   NQNV  NLS  ENIC  NDV  MDV

      1  2.4750E+00  1.7416E-13  4.3539E-15  1.0000E-01  6.2725E-10  1.0000E+00 -1.4459E-13 -1.4459E-13    0    0     0    0    1
*** USER    INFORMATION MESSAGE 6186,
    *** SOLUTION HAS CONVERGED ***

        SUBID    4     LOOPID   25     LOAD STEP    4.000     LOAD FACTOR    1.00000

^^^ DMAP INFORMATION MESSAGE 9005 (NLSCSH) -    THE SOLUTION FOR LOOPID=          25 IS SAVED FOR RESTART
```

Listing 8-48 Input Data for Example HA145KR

```
    N A S T R A N    F I L E    M A N A G E M E N T    S E C T I O N    E C H O


RESTART VERS=1 KEEP
                                                                                                                         PAGE     3
    N A S T R A N    E X E C U T I V E    C O N T R O L    D E C K    E C H O


ID MSC, HA145KR
TIME 5 $ CPU TIME IN MINUTES
SOL 145 $ FLUTTER
CEND



EXAMPLE HA145KR: THREE BEAM HEATED WING                                                                                  PAGE     4
 GEOMETRIC NONLINEAR ANALYSIS AND FLUTTER

                                C A S E    C O N T R O L    D E C K    E C H O
            CARD
            COUNT
             1      TITLE = EXAMPLE HA145KR: THREE BEAM HEATED WING
             2      SUBTI = GEOMETRIC NONLINEAR ANALYSIS AND FLUTTER
             3        ECHO        = BOTH
             4        TEMP(INIT) = 1 $ INITIAL TEMPERATURE
             5      PARAM,NMLOOP,10
             6      $ SPECIFIES LOOP IDENTIFICATION NUMBER IN SOL 153 FOR UPDATED STIFFNESS
             7        SPC         = 1 $ ADDITIONAL CONSTRAINTS
             8        METHOD      = 10 $ MGIV REAL EIGENVALUE METHOD FOR VIBES
             9        SVEC        = ALL $ REQUEST VIBRATION MODES
            10        FMETHOD     = 20 $ PK-FLUTTER METHOD
            11      $
            12      OUTPUT(XYOUT)
            13        CSCALE 2.0
            14        PLOTTER NASTRAN
            15        CURVELINESYMBOL = 6
            16        YTTITLE = DAMPING  G
            17        YBTITLE = FREQUENCY  F HZ
            18        XTITLE  = VELOCITY  V (FT/S)
            19        XMIN  =    0.
            20        XMAX  = 300.
            21        YTMIN =  -1.0
            22        YTMAX =  +1.0
            23        YBMIN =   0.
            24        YBMAX =  10.
            25        XTGRID LINES = YES
            26        XBGRID LINES = YES
            27        YTGRID LINES = YES
            28        YBGRID LINES = YES
            29        UPPER TICS  = -1
            30        TRIGHT TICS = -1
            31        BRIGHT TICS = -1
            32        XYPLOT VG / 1(G,F) 2(G,F)
            33      $
            34      BEGIN BULK
```

Listing 8-48 Input Data for Example HA145KR (Continued)

```
EXAMPLE HA145KR: THREE BEAM HEATED WING                                                          PAGE     5
 GEOMETRIC NONLINEAR ANALYSIS AND FLUTTER

                                 I N P U T   B U L K   D A T A   D E C K   E C H O

                         .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                         $
                         $       GRID POINT WEIGHT GENERATOR
                         $
                         PARAM   GRDPNT  100
                         $                                                                       $
                         $       ADDITIONAL CONSTRAINTS FOR CANTILEVER WING
                         $
                         $       SID     C       G1      G2      ETC
                         SPC1    1       35      200
                         $
                         $           *  *  *  AERODYNAMIC DATA  *  *  *
                         $
                         $       THE AERO ENTRY GIVES BASIC AERODYNAMIC PARAMETERS FOR UNSTEADY
                         $       AERODYNAMICS.
                         $
                         $       ACSID   VELOCITY REFC    RHOREF  SYMXZ   SYMXY
                         AERO                    20.     1.1463-7 1       0
                         $
                         $       THE CAERO1 ENTRY IS USED FOR DOUBLET-LATTICE AND ZONA51         $
                         $       AERODYNAMICS.  LISTED ARE ITS PAERO ENTRY ID AND THE            $
                         $       COORDINATE SYSTEM FOR LOCATING THE INBOARD AND OUTBOARD         $
                         $       LEADING EDGE POINTS (1 AND 4).  NSPAN AND NCHORD, OR LSPAN      $
                         $       AND LCHORD, ARE USED TO PARTITION THE WING INTO AERODYNAMIC     $
                         $       PANELS, THE FORMER FOR UNIFORMLY SPACED PANELS AND THE          $
                         $       LATTER FOR NON-UNIFORMLY SPACED PANELS.  IGID IS THE ID OF      $
                         $       ITS ASSOCIATED INTERFERENCE GROUP.  THE CONTINUATION ENTRY      $
                         $       DEFINES POINTS 1 AND 4, THE ROOT CHORD AND TIP CHORD.           $
                         $       THE BOXES FORMED BY THE GRID LINES WILL BE NUMBERED             $
                         $       BEGINNING WITH EID SO CHOOSE A NUMBER THAT IS UNIQUE,           $
                         $       AND IS GREATER THAN ALL STRUCTURAL GRID, SCALAR AND             $
                         $       EXTRA POINT IDS.                                                $
                         $                                                                       $
                         $       EID     PID     CP      NSPAN   NCHORD  LSPAN   LCHORD  IGID
                         CAERO1  1001    1000            8       4                       1       +CAW
                         $      ( FWD LEFT POINT  )     CHORD  ( FWD RIGHT POINT   )     CHORD
                         $       X1      Y1      Z1      X12     X4      Y4      Z4      X14
                         +CAW    -5.     0.      0.      40.     -5.     100.    0.      40.
                         $                                                                       $
                         $        THE PAERO1 ENTRY IS REQUIRED EVEN THOUGH IT IS NON-FUNCTIONAL  $
                         $        (BECAUSE THERE ARE NO ASSOCIATED BODIES IN THIS EXAMPLE).      $
                         $                                                                       $
                         $       PID     B1      B2      B3      B4      B5      B6
                         PAERO1  1000
                         $                                                                       $
                         $       THE SPLINE2 ENTRY DEFINES A BEAM SPLINE FOR INTERPOLATING PANELS
                         $       AND BODIES FOR AEROELASTIC PROBLEMS.
                         $                                                                       $
                         $       EID     CAERO   ID1     ID2     SETG    DZ      DTOR    CID
                         SPLINE2 1001    1001    1001    1032    1100    0.      1.0     1       +SPL
                         +SPL    -1.0    -1.0
                         $
                         $        THE SET1 ENTRY DEFINES THE SETS OF STRUCTURAL GRID POINTS      $
                         $        TO BE USED BY THE BEAM SPLINE FOR INTERPOLATION.               $
                         $                                                                       $
                         $       SID     G1      G2      G3      G4
                         SET1    1100    100     THRU    105     300     THRU    305
                         $
                         $       THE MKAERO1 ENTRY PROVIDES A TABLE OF MACH NUMBERS AND REDUCED
                         $       FREQUENCIES FOR AERODYNAMIC MATRIX CALCULATION.
                         $
                         $       M1      M2      ETC
                         MKAERO1 0.                                                              +MK
                         $        K1     K2      K3      K4      K5      ETC
                         +MK     .001    .1      .2      .5      1.0
                         $                                                                       $
```

Listing 8-48 Input Data for Example HA145KR (Continued)

```
$                                                                       $
$                 * * VIBRATION SOLUTION PARAMETERS * *                 $
$                                                                       $
$        THE EIGR ENTRY SPECIFIES THE METHOD OF EXTRACTING THE EIGEN-   $
$        SOLUTIONS OF THE STRUCTURE IN A VACUUM; IN THIS CASE THE       $
$        MODIFIED GIVENS METHOD.  FOUR MODES ARE DESIRED, NORMAL-       $
$        IZED ON THE MAXIMUM DISPLACEMENTS.                             $
$                                                                       $
$       SID     METHOD  F1      F2              NO                      $
EIGR    10      MGIV    0.      25.             4                       +EGR
$       NORM    G       C                                               $
+EGR    MAX
$
$                 * * FLUTTER SOLUTION PARAMETERS * *                   $
$                                                                       $
$        THE FLUTTER ENTRY DEFINES THE METHOD OF SOLUTION, IDENTIFIES   $
$        THE FLFACT ENTRIES THAT FOLL0W, SPECIFIES THE INTERPOLATION    $
$        METHOD, THE NUMBER OF ROOTS DESIRED IN THE OUTPUT AND THE      $
$        CRITERION FOR CONVERGENCE (DEFAULT IS 10-3).                   $
$                                                                       $
$       SID     METHOD  DENS    MACH    VEL     IMETH   NVALUE  EPS     $
FLUTTER 20      PK      1       2       3               4       0.01
$                                                                       $
$        FLFACT ENTRIES ARE USED TO SPECIFY DENSITY RATIOS, MACH NO.S   $
$        AND REDUCED FREQUENCIES/VELOCITIES FOR FLUTTER ANALYSES.       $
$        NEGATIVE VELOCITIES ARE SIGNALS TO COMPUTE AND PRINT EIGEN-    $
$        VECTORS.                                                       $
$                                                                       $
$       SID     F1      F2      F3      F4      F5      F6      F7      $
FLFACT  1       1.0                                                     DENSITY
FLFACT  2       0.                                                      MACH NO.
FLFACT  3       600.    1200.   1800.   1920.   2400.   3000.   3600.   VELOCITY
$                                                                       $
$       THE PARAMETER LMODES IS THE LOWEST NUMBER OF MODES TO BE
$       USED IN A MODAL FORMULATION.
$
PARAM   LMODES  4
$
$       IN A FLUTTER ANALYSIS, THE VELOCITIES ARE DIVIDED BY THE
$       PARAMETER VREF TO CONVERT UNITS OF VELOCITY IN THE OUTPUT
$       FLUTTER SUMMARY TABLE.
$
PARAM   VREF    12.0
$
ENDDATA
INPUT BULK DATA CARD COUNT =     110
```

Listing 8-49 Sorted Bulk Data for Example HA145KR

```
EXAMPLE HA145KR: THREE BEAM HEATED WING                                                                   PAGE     8
 GEOMETRIC NONLINEAR ANALYSIS AND FLUTTER

                                             S O R T E D   B U L K   D A T A   E C H O
            CARD
            COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
               1-        AERO                    20.     1.1463-71       0
               2-        CAERO1  1001    1000            8       4                       1       +CAW
               3-        +CAW    -5.     0.      0.      40.     -5.     100.    0.      40.
               4-        CBEAM   101     100     100     101     0.      0.      1.
               5-        CBEAM   102     100     101     102     0.      0.      1.
               6-        CBEAM   103     100     102     103     0.      0.      1.
               7-        CBEAM   104     100     103     104     0.      0.      1.
               8-        CBEAM   105     100     104     105     0.      0.      1.
               9-        CBEAM   201     100     200     201     0.      0.      1.
              10-        CBEAM   202     100     201     202     0.      0.      1.
              11-        CBEAM   203     100     202     203     0.      0.      1.
              12-        CBEAM   204     100     203     204     0.      0.      1.
              13-        CBEAM   205     100     204     205     0.      0.      1.
              14-        CBEAM   301     100     300     301     0.      0.      1.
              15-        CBEAM   302     100     301     302     0.      0.      1.
              16-        CBEAM   303     100     302     303     0.      0.      1.
              17-        CBEAM   304     100     303     304     0.      0.      1.
              18-        CBEAM   305     100     304     305     0.      0.      1.
              19-        CONM2   101     101     0       5.0
              20-        CONM2   102     102     0       5.0
              21-        CONM2   103     103     0       5.0
              22-        CONM2   104     104     0       5.0
              23-        CONM2   105     105     0       5.0
              24-        CONM2   201     201     0       20.0
              25-        CONM2   202     202     0       20.0
              26-        CONM2   203     203     0       20.0
              27-        CONM2   204     204     0       20.0
              28-        CONM2   205     205     0       20.0
              29-        CONM2   301     301     0       25.0
              30-        CONM2   302     302     0       25.0
              31-        CONM2   303     303     0       25.0
              32-        CONM2   304     304     0       25.0
              33-        CONM2   305     305     0       25.0
              34-        CORD2R  1       0       20.     0.      0.      20.     0.      10.     +CRD
              35-        +CRD    30.     0.      0.
              36-        EIGR    10      MGIV    0.      25.             4                       +EGR
              37-        +EGR    MAX
              38-        FLFACT  1       1.0                                                     DENSITY
              39-        FLFACT  2       0.                                                      MACH NO.
              40-        FLFACT  3       600.    1200.   1800.   1920.   2400.   3000.   3600.   VELOCITY
              41-        FLUTTER 20      PK      1       2       3               4       0.01
              42-        GRID    100             0.      0.      0.
              43-        GRID    101             0.      20.     0.
              44-        GRID    102             0.      40.     0.
              45-        GRID    103             0.      60.     0.
              46-        GRID    104             0.      80.     0.
              47-        GRID    105             0.      100.    0.
              48-        GRID    200             10.     0.      0.              1246
              49-        GRID    201             10.     20.     0.
              50-        GRID    202             10.     40.     0.
              51-        GRID    203             10.     60.     0.
              52-        GRID    204             10.     80.     0.
              53-        GRID    205             10.     100.    0.
              54-        GRID    300             20.     0.      0.
              55-        GRID    301             20.     20.     0.
              56-        GRID    302             20.     40.     0.
              57-        GRID    303             20.     60.     0.
              58-        GRID    304             20.     80.     0.
              59-        GRID    305             20.     100.    0.
              60-        MAT1    1       10.3+6  3.9+6                   1.244-5 0.0
              61-        MATT1   1       1       2                       3
              62-        MKAERO1 0.                                                              +MK
              63-        +MK     .001    .1      .2      .5      1.0
              64-        NLPARM  10      1               AUTO    1               PW      YES
              65-        NLPARM  20      4               AUTO    1               PW      YES
              66-        NLPARM  30      10              AUTO    1               PW      YES
              67-        NLPARM  40      10              AUTO    1               PW      YES
              68-        PAERO1  1000
              69-        PARAM   GRDPNT  100
              70-        PARAM   LGDISP  1
```

Listing 8-49 Sorted Bulk Data for Example HA145KR (Continued)

```
   71-        PARAM   LMODES  4
   72-        PARAM   VREF    12.0
   73-        PARAM   WTMASS  .0025907
   74-        PBEAM   100     1       2.0     1.0     100.    0.0     0.1             +PB100
   75-        +PB100  NO      1.0                                                     $
   76-        RBAR    100     200     100     123456
   77-        RBAR    105     105     205     123456
   78-        RBAR    200     200     300     123456
   79-        RBAR    205     205     305     123456
   80-        SET1    1100    100     THRU    105     300     THRU    305
   81-        SPC1    1       35      200
   82-        SPLINE2 1001    1001    1001    1032    1100    0.      1.0     1       +SPL
   83-        +SPL    -1.0    -1.0
   84-        TABLEM1 1                                                               +TABM1
   85-        +TABM1  0.0     10.3+6  200.0   10.3+6  ENDT
   86-        TABLEM1 2                                                               +TABM2
   87-        +TABM2  0.0     3.9+6   200.0   3.9+6   ENDT
   88-        TABLEM1 3                                                               +TABM3
   89-        +TABM3  0.0     1.244-5 200.0   1.244-5 ENDT
   90-        TEMP    2       100     0.001   101     0.001   102     0.001
   91-        TEMP    2       103     0.001   104     0.001   105     0.001
   92-        TEMP    2       300     0.001   301     0.001   302     0.001
   93-        TEMP    2       303     0.001   304     0.001   305     0.001
   94-        TEMP    3       100     50.     101     50.     102     50.
   95-        TEMP    3       103     50.     104     50.     105     50.
   96-        TEMP    3       300     50.     301     50.     302     50.
   97-        TEMP    3       303     50.     304     50.     305     50.
   98-        TEMP    4       100     150.    101     150.    102     150.
   99-        TEMP    4       103     150.    104     150.    105     150.
  100-        TEMP    4       300     150.    301     150.    302     150.
  101-        TEMP    4       303     150.    304     150.    305     150.
  102-        TEMP    5       100     200.    101     200.    102     200.
  103-        TEMP    5       103     200.    104     200.    105     200.
  104-        TEMP    5       300     200.    301     200.    302     200.
  105-        TEMP    5       303     200.    304     200.    305     200.
  106-        TEMPD   1       0.
  107-        TEMPD   2       0.
  108-        TEMPD   3       0.
  109-        TEMPD   4       0.
  110-        TEMPD   5       0.
              ENDDATA
        TOTAL COUNT=      111
```

Listing 8-50 Output for Example HA145KR

```
EXAMPLE HA145KR: THREE BEAM HEATED WING                                                                 PAGE    12
  GEOMETRIC NONLINEAR ANALYSIS AND FLUTTER

                        O U T P U T   F R O M   G R I D   P O I N T   W E I G H T   G E N E R A T O R
                                                          REFERENCE POINT =      100
                                                                     M O
                   *  2.500000E+02  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00 -1.500000E+04 *
                   *  0.000000E+00  2.500000E+02  0.000000E+00  0.000000E+00  0.000000E+00  3.500000E+03 *
                   *  0.000000E+00  0.000000E+00  2.500000E+02  1.500000E+04 -3.500000E+03  0.000000E+00 *
                   *  0.000000E+00  0.000000E+00  1.500000E+04  1.100000E+06 -2.100000E+05  0.000000E+00 *
                   *  0.000000E+00  0.000000E+00 -3.500000E+03 -2.100000E+05  6.000000E+04  0.000000E+00 *
                   * -1.500000E+04  3.500000E+03  0.000000E+00  0.000000E+00  0.000000E+00  1.160000E+06 *
                                                                      S
                                    *  1.000000E+00  0.000000E+00  0.000000E+00 *
                                    *  0.000000E+00  1.000000E+00  0.000000E+00 *
                                    *  0.000000E+00  0.000000E+00  1.000000E+00 *
                          DIRECTION
                     MASS AXIS SYSTEM (S)     MASS              X-C.G.        Y-C.G.        Z-C.G.
                              X            2.500000E+02      0.000000E+00  6.000000E+01  0.000000E+00
                              Y            2.500000E+02      1.400000E+01  0.000000E+00  0.000000E+00
                              Z            2.500000E+02      1.400000E+01  6.000000E+01  0.000000E+00
                                                                     I(S)
                                    *  2.000001E+05  0.000000E+00  0.000000E+00 *
                                    *  0.000000E+00  1.100000E+04  0.000000E+00 *
                                    *  0.000000E+00  0.000000E+00  2.110001E+05 *
                                                                     I(Q)
                                    *  2.000001E+05                             *
                                    *                1.100000E+04               *
                                    *                              2.110001E+05 *
                                                                      Q
                                    *  1.000000E+00  0.000000E+00  0.000000E+00 *
                                    *  0.000000E+00  1.000000E+00  0.000000E+00 *
                                    *  0.000000E+00  0.000000E+00  1.000000E+00 *


                                          R E A L   E I G E N V A L U E S
MODE    EXTRACTION      EIGENVALUE            RADIANS             CYCLES            GENERALIZED         GENERALIZED
 NO.       ORDER                                                                        MASS              STIFFNESS
     1        28        3.128240E+02        1.768683E+01        2.814946E+00        3.176117E-01        9.935656E+01
     2        29        1.259820E+03        3.549394E+01        5.649036E+00        5.702050E-02        7.183556E+01
     3        30        1.219031E+04        1.104097E+02        1.757225E+01        2.102801E-01        2.563379E+03
     4        31        2.912658E+04        1.706651E+02        2.716220E+01        1.428661E-01        4.161202E+03
     5        32        5.821704E+04        2.412821E+02        3.840124E+01        0.0                 0.0
     6         1        6.004134E+04        2.450333E+02        3.899827E+01        0.0                 0.0
     7        33        1.163347E+05        3.410787E+02        5.428436E+01        0.0                 0.0
     8        34        1.703640E+05        4.127518E+02        6.569149E+01        0.0                 0.0
     9        35        3.409595E+05        5.839174E+02        9.293333E+01        0.0                 0.0
    10        39        5.294054E+05        7.276025E+02        1.158015E+02        0.0                 0.0

  EIGENVALUE =  3.128240E+02
      CYCLES =  2.814946E+00         R E A L   E I G E N V E C T O R   N O .          1

  POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
       101      G      0.0            0.0            7.296664E-03   1.147712E-03  -6.525782E-03   0.0
       102      G      0.0            0.0            5.967955E-02   4.378497E-03  -1.305156E-02   0.0
       103      G      0.0            0.0            1.893437E-01   8.654088E-03  -1.957735E-02   0.0
       104      G      0.0            0.0            4.037478E-01   1.261274E-02  -2.610313E-02   0.0
       105      G      0.0            0.0            6.836064E-01   1.502141E-02  -3.262891E-02   0.0
       201      G      0.0            0.0            8.162597E-02   7.159712E-03  -6.525782E-03   0.0
       202      G      0.0            0.0            2.609250E-01   1.033114E-02  -1.305156E-02   0.0
       203      G      0.0            0.0            4.842834E-01   1.184416E-02  -1.957735E-02   0.0
       204      G      0.0            0.0            7.324311E-01   1.300315E-02  -2.610313E-02   0.0
       301      G      0.0            0.0            7.558579E-02   7.616369E-03  -6.525782E-03   0.0
       302      G      0.0            0.0            2.987881E-01   1.434532E-02  -1.305156E-02   0.0
       303      G      0.0            0.0            6.301132E-01   1.815709E-02  -1.957735E-02   0.0
       304      G      0.0            0.0            1.000000E+00   1.817642E-02  -2.610313E-02   0.0
```

Listing 8-50 Output for Example HA145KR (Continued)

```
       EIGENVALUE =  1.259820E+03
           CYCLES =  5.649036E+00        R E A L   E I G E N V E C T O R   N O .          2

       POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
            101      G      0.0            0.0            7.621557E-02   7.430675E-03   1.214537E-02   0.0
            102      G      0.0            0.0            2.826044E-01   1.264947E-02   2.429073E-02   0.0
            103      G      0.0            0.0            5.571611E-01   1.408163E-02   3.643610E-02   0.0
            104      G      0.0            0.0            8.194914E-01   1.152371E-02   4.858146E-02   0.0
            105      G      0.0            0.0            1.000000E+00   6.226471E-03   6.072683E-02   0.0
            201      G      0.0            0.0            3.314885E-02   2.887687E-03   1.214537E-02   0.0
            202      G      0.0            0.0            1.045081E-01   4.052567E-03   2.429073E-02   0.0
            203      G      0.0            0.0            1.906229E-01   4.492481E-03   3.643610E-02   0.0
            204      G      0.0            0.0            2.840572E-01   4.908875E-03   4.858146E-02   0.0
            301      G      0.0            0.0           -5.506493E-02  -4.938958E-03   1.214537E-02   0.0
            302      G      0.0            0.0           -1.724937E-01  -6.086522E-03   2.429073E-02   0.0
            303      G      0.0            0.0           -2.733315E-01  -3.423079E-03   3.643610E-02   0.0
            304      G      0.0            0.0           -2.944551E-01   1.503537E-03   4.858146E-02   0.0

       EIGENVALUE =  1.219031E+04
           CYCLES =  1.757225E+01        R E A L   E I G E N V E C T O R   N O .          3

       POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
            101      G      0.0            0.0            2.114693E-01   1.829058E-02   1.016710E-02   0.0
            102      G      0.0            0.0            6.138327E-01   1.876361E-02   2.033420E-02   0.0
            103      G      0.0            0.0            8.594995E-01   3.729860E-03   3.050130E-02   0.0
            104      G      0.0            0.0            7.216847E-01  -1.755753E-02   4.066840E-02   0.0
            105      G      0.0            0.0            1.925080E-01  -3.350382E-02   5.083550E-02   0.0
            201      G      0.0            0.0            9.502361E-02   7.499272E-03   1.016710E-02   0.0
            202      G      0.0            0.0            2.414319E-01   5.829746E-03   2.033420E-02   0.0
            203      G      0.0            0.0            2.899759E-01  -1.828819E-03   3.050130E-02   0.0
            204      G      0.0            0.0            1.397008E-01  -1.396354E-02   4.066840E-02   0.0
            301      G      0.0            0.0            4.305721E-01   3.344695E-02   1.016710E-02   0.0
            302      G      0.0            0.0            1.000000E+00   1.578493E-02   2.033420E-02   0.0
            303      G      0.0            0.0            9.029533E-01  -2.593060E-02   3.050130E-02   0.0
            304      G      0.0            0.0            8.058599E-02  -4.982566E-02   4.066840E-02   0.0

       EIGENVALUE =  2.912658E+04
           CYCLES =  2.716220E+01        R E A L   E I G E N V E C T O R   N O .          4

       POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
            101      G      0.0            0.0           -3.828819E-02  -3.670634E-03  -6.925469E-03   0.0
            102      G      0.0            0.0           -1.390392E-01  -6.163489E-03  -1.385094E-02   0.0
            103      G      0.0            0.0           -2.800803E-01  -7.938215E-03  -2.077641E-02   0.0
            104      G      0.0            0.0           -4.677928E-01  -1.141089E-02  -2.770188E-02   0.0
            105      G      0.0            0.0           -7.755890E-01  -2.079395E-02  -3.462734E-02   0.0
            201      G      0.0            0.0            4.484498E-01   3.311279E-02  -6.925469E-03   0.0
            202      G      0.0            0.0            1.000000E+00   1.539818E-02  -1.385094E-02   0.0
            203      G      0.0            0.0            9.462705E-01  -2.081512E-02  -2.077641E-02   0.0
            204      G      0.0            0.0            2.712620E-01  -4.076002E-02  -2.770188E-02   0.0
            301      G      0.0            0.0           -1.499004E-01  -1.053164E-02  -6.925469E-03   0.0
            302      G      0.0            0.0           -2.854689E-01  -5.220476E-04  -1.385094E-02   0.0
            303      G      0.0            0.0           -1.589953E-01   1.127049E-02  -2.077641E-02   0.0
            304      G      0.0            0.0            4.717688E-02   5.187527E-03  -2.770188E-02   0.0

  A ZERO FREQUENCY ROOT HAS EMERGED.  WHEN THE MACH NO., DENSITY AND VELOCITY ARE COMPATIBLE
  IT MAY BE INTERPRETED TWO WAYS DEPENDING ON THE SIGN OF THE REAL PART:
    1. (-) A MODE IS CRITICALLY DAMPED, OR,
    2. (+) THE SYSTEM IS DIVERGING.
  ONLY THE MOST CRITICAL ( that is, MOST POSITIVE REAL ROOTS )  ARE PRINTED IN THE FLUTTER SUMMARY.
  FOR INFORMATIONAL PURPOSES, THE REMAINING REAL ROOTS ARE PRINTED HERE.

       LESS CRITICAL REAL ROOTS FOR LOOP    6      MACH         VELOCITY        DENSITY
                                               0.00000E+00    3.00000E+03    1.00000E+00

          KFREQ          DAMPING                COMPLEX EIGENVALUE

         0.0000     -1.6773781E-01       -1.7439867E+01         0.0000000E+00
         0.0000     -8.3181366E-02       -8.6484489E+00         0.0000000E+00

       LESS CRITICAL REAL ROOTS FOR LOOP    7      MACH         VELOCITY        DENSITY
                                               0.00000E+00    3.60000E+03    1.00000E+00

          KFREQ          DAMPING                COMPLEX EIGENVALUE

         0.0000     -2.9823565E-01       -3.7209431E+01         0.0000000E+00
         0.0000      1.2051423E-01        1.5035982E+01         0.0000000E+00
```

Listing 8-50 Output for Example HA145KR (Continued)

```
                                        FLUTTER  SUMMARY
 POINT =    1     MACH NUMBER =  0.0000     DENSITY RATIO =  1.0000E+00     METHOD = PK

 KFREQ          1./KFREQ        VELOCITY         DAMPING        FREQUENCY           COMPLEX   EIGENVALUE
  0.2951     3.3883512E+00   5.0000000E+01   -3.3877235E-02   2.8182724E+00   -2.9994443E-01    1.7707727E+01
  0.1519     6.5851388E+00   1.0000000E+02   -7.9980932E-02   2.9002566E+00   -7.2874027E-01    1.8222851E+01
  0.1128     8.8682280E+00   1.5000000E+02   -2.0572214E-01   3.2303958E+00   -2.0877893E+00    2.0297176E+01
  0.1096     9.1269636E+00   1.6000000E+02   -3.5693970E-01   3.3480740E+00   -3.7543933E+00    2.1036570E+01
  0.0725     1.3790782E+01   2.0000000E+02   -1.0542395E+00   2.7697618E+00   -9.1734266E+00    1.7402927E+01
  0.0000     9.9999996E+24   2.5000000E+02   -8.3181366E-02   0.0000000E+00   -8.6484489E+00    0.0000000E+00
  0.0000     9.9999996E+24   3.0000000E+02    1.2051423E-01   0.0000000E+00    1.5035982E+01    0.0000000E+00
 POINT =    2     MACH NUMBER =  0.0000     DENSITY RATIO =  1.0000E+00     METHOD = PK

 KFREQ          1./KFREQ        VELOCITY         DAMPING        FREQUENCY           COMPLEX   EIGENVALUE
  0.5764     1.7347887E+00   5.0000000E+01   -2.3110120E-02   5.5045872E+00   -3.9964724E-01    3.4586342E+01
  0.2665     3.7522483E+00   1.0000000E+02   -5.5297688E-02   5.0899062E+00   -8.8423282E-01    3.1980825E+01
  0.1435     6.9690208E+00   1.5000000E+02   -5.0988071E-02   4.1107478E+00   -6.5847504E-01    2.5828592E+01
  0.1243     8.0450697E+00   1.6000000E+02    5.2899200E-02   3.7983196E+00    6.3123417E-01    2.3865547E+01
  0.0881     1.1355899E+01   2.0000000E+02    4.5322740E-01   3.3636425E+00    4.7893424E+00    2.1134390E+01
  0.0567     1.7638226E+01   2.5000000E+02    8.1069690E-01   2.7069888E+00    6.8943744E+00    1.7008512E+01
  0.0366     2.7339989E+01   3.0000000E+02    5.2598155E-01   2.0956767E+00    3.4629376E+00    1.3167525E+01
 POINT =    3     MACH NUMBER =  0.0000     DENSITY RATIO =  1.0000E+00     METHOD = PK

 KFREQ          1./KFREQ        VELOCITY         DAMPING        FREQUENCY           COMPLEX   EIGENVALUE
  1.8269     5.4737139E-01   5.0000000E+01   -3.7979512E-03   1.7445736E+01   -2.0815581E-01    1.0961479E+02
  0.9106     1.0982338E+00   1.0000000E+02   -1.1912663E-02   1.7390278E+01   -6.5082657E-01    1.0926634E+02
  0.6069     1.6478065E+00   1.5000000E+02   -1.9875834E-02   1.7385468E+01   -1.0855795E+00    1.0923612E+02
  0.5690     1.7575625E+00   1.6000000E+02   -2.1441333E-02   1.7386435E+01   -1.1711491E+00    1.0924220E+02
  0.4553     2.1962969E+00   2.0000000E+02   -2.7598601E-02   1.7391630E+01   -1.5079162E+00    1.0927483E+02
  0.3644     2.7441893E+00   2.5000000E+02   -3.5089836E-02   1.7399120E+01   -1.9180437E+00    1.0932190E+02
  0.3038     3.2911725E+00   3.0000000E+02   -4.2351328E-02   1.7408926E+01   -2.3162684E+00    1.0938351E+02
 POINT =    4     MACH NUMBER =  0.0000     DENSITY RATIO =  1.0000E+00     METHOD = PK

 KFREQ          1./KFREQ        VELOCITY         DAMPING        FREQUENCY           COMPLEX   EIGENVALUE
  2.8423     3.5182920E-01   5.0000000E+01   -4.7117035E-05   2.7141851E+01   -4.0176059E-03    1.7053729E+02
  1.4202     7.0411587E-01   1.0000000E+02   -5.5711548E-04   2.7124218E+01   -4.7473621E-02    1.7042650E+02
  0.9463     1.0567598E+00   1.5000000E+02   -1.0402703E-03   2.7109175E+01   -8.8595644E-02    1.7033197E+02
  0.8871     1.1273248E+00   1.6000000E+02   -1.1345085E-03   2.7106424E+01   -9.6611738E-02    1.7031470E+02
  0.7094     1.4097354E+00   2.0000000E+02   -1.5126284E-03   2.7095285E+01   -1.2875849E-01    1.7024471E+02
  0.5672     1.7631882E+00   2.5000000E+02   -1.9833411E-03   2.7079626E+01   -1.6872910E-01    1.7014632E+02
  0.4723     2.1172702E+00   3.0000000E+02   -2.4335631E-03   2.7061155E+01   -2.0688967E-01    1.7003026E+02
```

Use of External Superelements in Aerodynamic Analysis (Examples HA145SS7 and HA145SS8)

This example talks about the use of external superelements so as to avoid writing the same external structure in the input deck multiple times. The input requirements for the three types of external superelement runs are best explained by example. The **generation** run is in `ha145ss7.dat` while the **assembly** data is in `ha145ss8.dat`. The external superelement for this example consists of an engine model, analyzed in a multilevel superelement configuration. In principle, an external superelement can be a very large, detailed model, although the demonstration model is small. The scenario is that this model is provided to the aircraft developer by the engine manufacturer. The aircraft developer attaches this engine model at several places in one aircraft model and plans to attach it to many other aircraft models over time. The aircraft modeler does not want to modify the engine model, even inadvertently. He also wants the IDs of the grid points and elements of the aircraft to be independent of the IDs used in the engine model. The latter requirement is met by making the engine model a part superelement. The former requirement is met by analyzing the engine model once in a stand-alone generation run, then attaching the boundary matrices which result from this run to many other models. The cost of reducing the engine model is paid only once, and the engine model cannot be changed inadvertently on subsequent runs.

Generation Run

The engine model is analyzed and reduced to its boundary matrices in the generation run. This run places the boundary matrices in an engine model database. In order to easily access this database in the next Assembly run, the user can include "scr=no" at the end of the Nastran run command. This database and bulk data entries which define the geometry and connectivity of the interface points are added to a model where the total aircraft is analyzed. In this example, this engine model is attached to an aircraft model of a swept-forward wing and a canard. This model was derived from model HA200A (see Chapter 10: Aeroelastic Design Sensitivities and Optimization). Several product improvements were made to the model, including the addition of engine mounting brackets at each wing tip.

The input data file is shown in Listing 8-51. ASSIGN statements are placed in the File Management Section (FMS) to provide permanent storage of the database. EXTSEOUT is placed in Case Control to request that the reduced matrices be stored in matrix format directly on the database, rather than on the other options of user tapes or DMIG entries. The engine is modeled about a point mid-way between its front mount points so that its grid points are symmetrical about the x-z plane which goes through this point. The engine is modeled as a box which hangs below the wing, attached by vertical links and a sway damper. Grid list superelements are used. The grid points on the lower surface are interior to superelement 2, the grid points on the upper surface are interior to superelement 1, and the attach points at the tops of the links are the only physical points in the residual structure of the component model. Generalized coordinates are attached to each superelement. They are used to transmit the dynamic characteristics of the superelements to the assembled model.

Listing 8-51 Input Data for Example HA145SS7

```
$ FILE ha145ss7.dat   GENERATE AN EXTERNAL SUPERELEMENT
$ ENGINE MODEL, MULTILEVEL SUPERELEMENT  MAG  27 AUG 97
$ INCLUDING AERO SPLINES   last revised 23 oct 97
ASSIGN MASTER='DBSDIR:eng.MASTER' $ SAVE FOR ha145ss8 RUN
ASSIGN DBALL ='DBSDIR:eng.DBALL'
ID MSC, ha145ss7 $ M_GOCKEL/KLK V70.5 19-FEB-1998
$ Modified 1-Apr-2003 v2003 rak
DIAG 8
SOL 145 $
$INCLUDE 'SEASPA.V70' $ remove before delivery with production system
CEND
TITLE = ENGINE MODEL, COMPLETE TO FUSELAGE ATTACH POINTS       ha145ss7
LABEL = USED AS EXTERNAL S.E. FOR EXTSP MODEL
ECHO   = BOTH
EXTSEOUT
METHOD   = 20
$ DO FLUTTER ON A STAND-ALONE VERIFICATION RUN
$FMETHOD  = 30 $ RUN A FLUTTER CASE FOR COMPONENT VERIFICATION
BEGIN BULK $
$ Set k6rot=0.0 to get pre V2003 results
param,k6rot,0.0
$ ALL GRID POINTS MEASURED FROM ENGINE CENTERLINE PLANE
$ FUSELAGE ATTACH POINTS
GRID,12,,0.0, -1.
GRID,14,,0.0, 1.
GRID,22,,5.0, -1.
GRID,24,,5.0, 1.
$ THE ATTACH POINTS IN THIS MODEL AND THE ha145ss8 MODEL MAY
$ HAVE GIDS AND Y LOCATIONS WHICH DIFFER, BUT THE RELATIVE SPACING OF
$ POINTS MUST BE IDENTICAL.
$ ENGINE GRID POINTS
GRID,112,,0.0, -1.,-4.
GRID,114,,0.0, -1.,-2.
GRID,116,,0.0, 1.,-4.
GRID,118,,0.0, 1.,-2.
GRID,122,,5.0, -1.,-4.
GRID,124,,5.0, -1.,-2.
GRID,126,,5.0, 1.,-4.
GRID,128,,5.0, 1.,-2.
```

Listing 8-51 Input Data for Example HA145SS7 (Continued)

```
$ ENGINE COWL.  FRONT AND BACK PANELS OPEN
CQUAD4,112,112,112,116,126,122 $ BOTTOM
CQUAD4,114,112,114,118,128,124 $ TOP
CQUAD4,116,112,116,126,128,118 $ SIDE
CQUAD4,122,112,122112,114,124 $ OTHER SIDE
PSHELL,112,1,.05,1
$ MOUNTING LINKS
CBAR,12,12,12,114,0.,1.,0.
CBAR,14,12,14,118,0.1.0.
CBAR,1418,12,114,118,0.0.1.
CBAR,22,12,22,124,0.1.0.
CBAR,24,12,24,128,0.1.0.
CBAR,2428,12,124,128,0.,0.,1.
PBAR,12,1,.1.2.3,.4
$ ADD SWAY BRACE TO SHOW FRONT FROM BACK, LH VS. RH, TEST BAA EFFECTS
CVISC,1218,121812,118
PVISC,1218.02
$MAT1   MID     E       G       NU      RHO,,GE
MAT1,   1       1.44+9  5.40+8,,1.0,,,.01
CONM2,1180,118,,100. $ ENGINE WEIGHTS
CONM2,1280,128,,100. $
CONM2,1140,114,,100. $
CONM2,1240,124,,100. $
$ PUT THE UPPER SURFACE IN S.E. 1 AND THE LOWER SURFACE IN S.E. 2
SESET,1,114,118,124,128
SESET,2,112,116,122,126
$ MAKE S.E. 2 THE TIP
DTI,SETREE,1,2,1,1,0
$ DON'T ALLOW UNUSED GEN. COORDS TO BE AUTOSPCD
SPCOFF1,0,701THRU720
SPOINT,701,THRU,720 $ GEN. COORDS
SEQSET1, 1,0,701THRU710 $ FOR CMS
SEQSET1, 2,0,711THRU 720
$  DATA FOR WIND TUNNEL VALIDATION RUN FOLLOWS.  NOT NEEDED FOR EXTERNAL S.E.
$MKAERO1 M1     M2      ETC                                             +MK
MKAERO1 0.90    1.20                                                    +MK
$+MK     K1     K2      K3      K4      K5      ETC
+MK     0.001   0.01    0.1     0.3     0.5     1.0
$       SID     METHOD  DENS    MACH    VEL     IMETH   NVALUE  EPS     $
FLUTTER 30      PK      1       2       3       S       8
$       SID     F1      F2      F3      F4      F5      F6      F7      $
FLFACT  1       1.0                                                     DENSITY
FLFACT  2       0.90                                                    MACH
FLFACT  3       1000.0  1100.0  1200.0  1300.0  1400.0  1500.0  1600.0  VELOCITY
FLUTTER 40      PK      11      12      13      S       8
FLFACT  11      1.0
FLFACT  12      1.20
FLFACT  13      1000.0  1100.0  1200.0  1300.0  1400.0  1500.0  1600.0
$       ACSID   VELOCITY REFC   RHOREF  SYMXZ   SYMXY
AERO    1               10.0    2.378-3
CORD2R,1,0 0.0.0.0.0.10.
,20.0.0. $ IDENTICAL TO BASIC.  EXTERNAL BASIC IS AT
$ CENTER POINT BETWEEN FRONT MOUNTS.  THIS ENTRY CHANGED WHEN ENGINE MODEL
$ MOVED TO WING TIP IN EXTSP INPUT FILE
PARAM   WTMASS  .031081
PARAM   AUNITS  .031081
PARAM,GRDPNT,0
$       EID     PID     CP      NSPAN   NCHORD  LSPAN   LCHORD  IGID
CAERO1  4001    1000            2       2                       1
$      ( FWD LEFT POINT  )     CHORD  ( FWD RIGHT POINT   )     CHORD
$       X1      Y1      Z1      X12     X4     Y4    Z4      X14
,0.0, 2., 2.5. 0.0, 4.,2.5.
$       PID     B1      B2      B3      B4      B5      B6
PAERO1  1000
EIGRL,20,,,5
$ PRINT DOF MAP FOR HOOKING UP DOF IN STEP 2 WITH EXTRN ENTRY
$ USETSEL=128 WILL PRINT ONLY ASET DOF
PARAM,USETPRT,0
PARAM,USETSEL,128 $ THIS VALUE PRINTS ONLY A-SET
$ PUT AIR ON THE TOP SURFACE
$EID    CAERO   ID1     ID2     SETG    DZ      DTOR    CID
SPLINE2,400140014001    4004    4001    0.      1.      0       +SPRW
$       DTHX    DTHY
+SPRW   -1.     -1.
$       SID     G1      G2      G3      G4
SET1    4001    114118124128
ENDDATA
```

The analysis set (a-set) of the residual structure defines the DOFs in the boundary matrices. It is the user's responsibility to ensure that the proper set is available. There are many ways to do this. A method that has been verified by testing is to turn off AUTOSPC for generalized coordinates with an SPCOFF entry listing the generalized coordinates. This avoids having the AUTOSPC function placing unused generalized DOFs on single point constraints, which makes them unavailable for assembly. Also apply SPCOFF to any boundary grid points which may have singular DOFs. Each boundary grid point must have 6 DOFs in the a-set, even when some of these DOFs are singular. The singularities are removed in the assembly run. The number of generalized coordinates in the a-set must match the number listed on SECONCT and EXTRN entries in the next run.

All CAERO-type data, that is, the CAEROi entries and other entries referenced on a CAEROi entry, and the spline data, is placed in the main Bulk Data Section because these are grid list superelements. In the superelement spline method for internal superelements (that is, list and part superelements in the same input file) it is necessary to place all CAEROi entries for the entire model in the main Bulk Data Section. This allows the columns of the spline matrices to be properly aligned. This requirement is relaxed for external superelements. The engine modeler inputs CAERO-type entries only for the components in his model. A device is added to the total aircraft model, described later, which performs this alignment function.

Assembly Run

Listing 8-52 shows portions of the `ha145ss8.dat` input data file. Listing 8-53 shows the bulk data statements used in all assembly superelements in `ha145ss8.inc`. The assembled aircraft model of `ha145ss8.dat` has an FMS section with ASSIGN statements for the databases created on this run, and to be used on the external superelement data recovery run. It also has ASSIGN statements for the database created on the prior generation run, given the logical names se3db and se4db on this run. DBLOCATE statements state that the a-set matrices of the residual structure of the engine model are to be treated as external superelement numbers 3 and 4 in the assembled model. The same database (and its associated matrices) is used to model both engines, duplicating the function of identical images with the older technology. PARAM, USETPRT, 0 is added the first time this model is run to print the correlation of the external sequence numbers of the aero points with their internal sequence number. This set can be seen in Listing 8-54 below. From the right and left engine models included in `ha145ss8.inc`, the first instances for these can be seen at internal IDs 161 and 201 below.

Listing 8-52 Portions of Input Deck for Example HA145SS8

```
$ FILE ha145ss8    TOTAL MODEL.  BRING IN ENGINES AS EXTERNAL S.E.S,
$ INCLUDING AERO SPLINES    last revised 23 oct 97
ASSIGN MASTER='DBSDIR:extsp.MASTER' $
ASSIGN DBALL ='DBSDIR:extsp.DBALL'  $
$ LOCATE S.E.S 3, 4 FROM S.E. 3'S DATABASE:
$ Run ha145ss7.dat with scr=no with DBSDIR=. to generate eng.*
ASSIGN SE3DB = 'eng.MASTER'
DBLOCATE DB=(EXTDB) CONVERT(SEID=3) LOGI=SE3DB $ USE AS RH ENGINE
DBLOCATE DB=(EXTDB) CONVERT(SEID=4) LOGI=SE3DB $ USE AS LH ENGINE
ID MSC, ha145ss8 $ M_GOCKEL/KLK V70.5 19-FEB-1998
$ Modified 31-Aug-1999 v707 abb
$ID MSC, HA200A $ E_JOHNSON V68  5-JUL-1994 MODIFIED BY MAG 9 APR 97
$ CHANGES IN LOWER CASE
$$$$$$$$  HANDBOOK FOR AEROELASTIC ANALYSIS EXAMPLE HA200A      $$$$$$$$
TIME 30 $ CPU TIME IN MINUTES
SOL 145 $ CHANGED TO RUN FLUTTER ONLY
CEND
```

Listing 8-52 Portions of Input Deck for Example HA145SS8 (Continued)

```
TITLE = EXAMPLE HA200A: 30 DEG FWD SWEPT WING WITH CANARD      ha145ss8
LABEL = BRING IN ENGINES AS EXTERNAL SUPERELEMENTS, INCLUDING SPLINES
ECHO   = BOTH
SPC    = 1
LABEL    = SUBSONIC FLUTTER ANALYSIS
SET 10   = 1,THRU,100000
DISP     = 10
METHOD   = 20
FMETHOD  = 30
PARAM, USETPRT, 0 $ PRINT THE K-SET NUMBERS
PARAM, OPGEOM, 0
PARAM, USETSTR1, K
BEGIN super $ THE WING AND WING STORES ARE IN S.E. 0
$ ENGINE ATTACH POINTS ON WING TIPS.  ENGINES ARE EXTERNAL SUPERELEMENTS
...
...
$ THE MAIN BULK DEFINES THE WINGS AND STORES, WHICH ARE IN S.E. 0
$ SUPERELEMENT 3 IS EXTERNAL (I.E. DBLOCATED)
$SEBULK SEID    TYPE    RSEID   METHOD  TOL     LOC
SEBULK,3,EXTERNAL,,manual,.1,no $ RH ENGINE
SEBULK,4,EXTERNAL,,manual,.1,no $ LH ENGINE
$SECONCT GIDA1GIDB1GIDA2GIDB2ETC.
SECONCT 3       0       .1      no                                      +
+       12      12      14      14      22      22      24      24      +
+       701     701     702     702     703     703     704     704     +
+       705     705     706     706     707     707     708     708     +
+       709     709     710     710     711     711     712     712     +
+       713     713     714     714     715     715     716     716     +
+       717     717     718     718     719     719     720     720
SECONCT 4       0       .1      no                                      +
+       11      11      13      13      21      21      23      23      +
+       721     721     722     722     723     723     724     724     +
+       725     725     726     726     727     727     728     728     +
+       729     729     730     730     731     731     732     732     +
+       733     733     734     734     735     735     736     736     +
+       737     737     738     738     739     739     740     740
SPOINT,701,THRU,720 $ ATTACH TO GEN. COORDS OF S.E. 3
SPOINT,721,THRU,740 $ ATTACH TO GEN. COORDS OF S.E. 4
$ SE 10 AND 20 ARE CONVENTIONAL PART SUPERELEMENTS
$ USE THE LOW LABOR METHOD FOR GEN. COORDS
SENQSET, 10,15
SENQSET, 20,15
INCLUDE 'ha145ss8.inc' $ COMMON DATA FOR ALL SUPERELEMENTS
...
...
$                   * * *  FLUTTER ANALYSIS  * * *
$mkaero moved to .cmn file
$       SID     METHOD  DENS    MACH    VEL     IMETH   NVALUE  EPS     $
FLUTTER 30      PK      1       2       3       S       8
$       SID     F1      F2      F3      F4      F5      F6      F7      $
FLFACT  1       1.0                                                     DENSITY
FLFACT  2       0.90                                                    MACH
FLFACT  3       1000.0  1100.0  1200.0  1300.0  1400.0  1500.0  1600.0  VELOCITY
FLUTTER 40      PK      11      12      13      S       8
FLFACT  11      1.0
FLFACT  12      1.20
FLFACT  13      1000.0  1100.0  1200.0  1300.0  1400.0  1500.0  1600.0
...
...
BEGIN SUPER=3 $ RH ENGINE AS EXTERNAL S.E.$$S.E. 3
PARAM,FIRSTKI, 161 $ INTERNAL SEQUENCE NUMBER OF FIRST AERO POINT
$ EXTRN DESCRIBES HOW TO HOOK UP THE DBLOCATED MATRICES TO
$ THE CURRENT MODEL.  NOTE THAT THE ORDER OF THE GRIDS MUST BE
$ IN ASET ASCENDING ORDER OF THE ORIGINAL PROBLEM.
$ (SEE USET PRINTOUT FROM RUN1.)
$EXTRNGIDCIDGIDCIDGIDCIDGIDCID
$GIDCID     (ETC)
EXTRN   12      123456  14      123456  22      123456  24      123456  +
+       701     0       702     0       703     0       704     0       +
+       705     0       706     0       707     0       708     0       +
+       709     0       710     0       711     0       712     0       +
+       713     0       714     0       715     0       716     0       +
+       717     0       718     0       719     0       720     0       +
+       720     0
$ DEFINE THE GEOMETRY OF THE EXTERNAL SUPERELEMENT INTERFACE POINTS
$ FUSELAGE ATTACH POINTS, MEASURED FROM AIRCRAFT CENTERLINE
$ INPUT AN AXIS SYSTEM AT CENTER OF FRONT MOUNTS, RH SIDE
```

Listing 8-52 Portions of Input Deck for Example HA145SS8 (Continued)

```
$ THIS CORDI ENTRY INPUT IN .CMN DECK
GRID,12,3,0.0,-1.
GRID,14,3,0.0,1.
GRID,22,3,5.0,-1.
GRID,24,3,5.0,1.
$ ORIGINAL DEFINITION OF GENERALIZED DOF
SPOINT,701,THRU,720 $ GEN. COORDS
$ USE SAME COMMON DATA USED ELSEWHERE
INCLUDE 'ha145ss8.inc' $
BEGIN SUPER=4 $ PORT ENGINE AS EXTERNAL S.E.$$S.E. 4
PARAM,FIRSTKI, 201 $ INTERNAL SEQUENCE NUMBER OF FIRST AERO POINT
$EXTRNGIDCIDGIDCIDGIDCID     GID     CID
EXTRN   11      123456  13      123456  21      123456  23      123456  +
+       721     0       722     0       723     0       724     0       +
+       725     0       726     0       727     0       728     0       +
+       729     0       730     0       731     0       732     0       +
+       733     0       734     0       735     0       736     0       +
+       737     0       738     0       739     0       740     0       +
+       740     0
$ THIS CORDI INPUT IN .CMN DECK
GRID,11,4,0.0,-1.
GRID,13,4,0.0,1.
GRID,21,4,5.0,-1.
GRID,23,4,5.0,1.
SPOINT,721,THRU,740 $ GEN. COORDS
INCLUDE 'ha145ss8.inc' $
BEGIN SUPER=10 $ THE FUSELAGE AND CANARD$$$S.E. 10
$       ID      CP      X1      X2      X3      CD      PS      SEID
GRID    90              15.     0.      0.
GRID    97              0.      0.      0.
GRID    98              10.     0.      0.
GRID    99              20.     0.      0.
GRID    100             30.     0.      0.
$                * * STRUCTURAL STIFFNESS PROPERTIES * *                 $
CBAR    101     100     97      98      0.      0.      1.
CBAR    102     100     98      90      0.      0.      1.
CBAR    103     100     90      99      0.      0.      1.
CBAR    104     100     99      100     0.      0.      1.
$       EID     G       CID     M       X1      X2      X3
CONM2   97      97      0       3000.0
CONM2   98      98      0       3000.0
CONM2   99      99      0       3000.0
CONM2   100     100     0       3000.0
$                  * BEAM SPLINE FIT ON THE CANARD *                     $
$                          * RIGHT SIDE *                                $
SPLINE2 1501    1000    1000    1007    1000    0.      1.      1       +SPRC
+SPRC   1.      -1.
SET1    1000    98      99
SPLINE2 2501    2000    2000    2007    1000    0.      1.      1       +SPLC
+SPLC   1.      -1.
INCLUDE 'ha145ss8.inc' $ COMMON DATA FOR ALL SUPERELEMENTS
BEGIN SUPER=20 $ THE FIN$$$$$S.E. 20
GRID    99              20.     0.      0.
GRID,100,,30.     0.      0. $ FUS. POINT
$                             * FIN GRID *                               $
GRID    310             32.88675+0.     5.
GRID    311             30.38675+0.     5.
GRID    312             35.38675+0.     5.
$                    * BEAM SPLINE FIT ON THE FIN *                      $
SPLINE2 3100    3100    3100    3115    3100    0.      1.      300     +SP2FI
+SP2FI  -1.     -1.
SET1    3100    99      100     311     312
$                           * FIN STRUCTURE *                            $
$       EID     PID     GA      GB      X1,GO   X2      X3
CBAR    310     103     100     310     0.      0.      1.
$       EID     GA      GB      CNA     CNB     CMA     CMB
$ FIN
CONM2   31100   311     0       30.0
CONM2   31200   312     0       20.0
RBAR    311     310     311     123456
RBAR    312     310     312     123456
PLOTEL, 3110    310     311
PLOTEL, 3120    310     312
INCLUDE 'ha145ss8.inc' $ COMMON DATA FOR ALL SUPERELEMENTS
ENDDATA
```

Listing 8-53 Common Bulk Data Statements for All Superelements in Example HA145SS8

```
$ FILE ha145ss8.cmn DATA IN COMMON BETWEEN ALL SUPERELEMENTS
$ LAST REVISED 23 OCT 97
$MKAERO1 M1      M2      ETC
MKAERO1 0.90    1.20
$       K1      K2      K3      K4      K5      ETC
,       0.001   0.01    0.1     0.3     0.5     1.0
$       ACSID   VELOCITY REFC   RHOREF  SYMXZ   SYMXY
AERO    1               10.0    2.378-3
$       PID     MID     A       I1      I2      J       NSM
PBAR    100     1       4.0     .347222 .30     1.0                     +PB1F
$       C1      C2      D1      D2      E1      E2      F1      F2
+PB1F   1.0     1.0     1.0     -1.0    -1.0    1.0     -1.0    -1.0    +PB2F
$       K1      K2      I12
+PB2F                   0.0
$       PID     MID     A       I1      I2      J       NSM
PBAR    103     3       1.5     0.173611+2.0    0.462963                +PB1V
$       C1      C2      D1      D2      E1      E2      F1      F2
+PB1V   0.5     3.0     0.5     -3.0    -0.5    3.0     -0.5    -3.0    +PB2V
$       K1      K2      I12
+PB2V                   0.0
$MAT1   MID     E       G       NU      RHO     A       TREF    GE      +MT
MAT1    1       1.44+9  5.40+8          0.0
PARAM   GRDPNT  90
PARAM   WTMASS  .031081
PARAM   AUNITS  .031081
$       CID     RID     A1      A2      A3      B1      B2      B3
CORD2R  1       0       12.5    0.      0.      12.5    0.      10.     +CRD1
$       C1      C2      C3
+CRD1   20.     0.      0.
$       CID     RID     A1      A2      A3      B1      B2      B3
CORD2R  100     0       15.0    0.0     0.0     15.0    0.0     -10.0   +CRD100
$       C1      C2      C3
+CRD100 0.0     0.0     0.0
$                       * WING AERODYNAMIC MODEL *                      $
$                           * RIGHT WING *
$       EID     PID     CP      NSPAN   NCHORD  LSPAN   LCHORD  IGID
CAERO1  1100    1000            8       4                       1       +CARW
$      ( FWD LEFT POINT  )     CHORD ( FWD RIGHT POINT   )     CHORD
$       X1      Y1      Z1      X12     X4         Y4   Z4      X14
+CARW   25.     0.      0.      10.     13.45299+20.    0.      10.
$       PID     B1      B2      B3      B4      B5      B6
PAERO1  1000
$                           * LEFT WING *
CAERO1  2100    1000            8       4                       1       +CALW
+CALW   13.45299-20.    0.      10.     25.     0.      0.      10.
$                      * CANARD AERODYNAMIC MODEL *                     $
$                            * RIGHT SIDE *
CAERO1  1000    1000            2       4                       1       +CARC
+CARC   10.     0.      0.      10.     10.     5.      0.      10.
$                            * LEFT SIDE *
CAERO1  2000    1000            2       4                       1       +CALC
+CALC   10.     -5.     0.      10.     10.     0.      0.      10.
$                       * FIN AERODYNAMIC MODEL *                       $
CAERO1  3100    1000            4       4                       1       +CA1FI
+CA1FI  30.7735 0.      10.     10.     25.     0.      0.      10.
$ RH ENGINE AIR
$       EID     PID     CP      NSPAN   NCHORD  LSPAN   LCHORD  IGID
CAERO1  4001    1000    4       2       2                       1
$      ( FWD LEFT POINT  )     CHORD ( FWD RIGHT POINT   )     CHORD
$       X1      Y1      Z1      X12     X4      Y4     Z4      X14
,0.0, 2., 2.5. 0.0, 4.,2.5.
$ LH ENGINE AIR
CAERO1  3001    1000    3       2       2                       1
,0.0, 2., 2.5. 0.0, 4.,2.5.
```

Listing 8-53 Common Bulk Data Statements for All Superelements in Example HA145SS8 (Continued)

```
$ ENGINE COORDINATE SYSTEMS
CORD2R,3,018.83795, 15.,0.18.83795, 15.,1.
,20.,15.,0. $ MID-POINT OF FRONT MOUNTS, STARBOARD
CORD2R,4,018.83795, -15.,0.18.83795, -15.,1.
,20.,-15.,0. $ MID-POINT OF FRONT MOUNTS, PORT
$                         * RIGHT WING SPLINE AXIS *                  $
$       $                     * CONTROL SURFACE HINGE LINES *                  $
$                            * CANARD *                               $
$       THE COORDINATE SYSTEM, CORD2R,1, REFERENCED BY THE AEROS ENTRY $
$       IS THE CANARD HINGE LINE, AND NEEDS NO FURTHER DEFINITION      $
$                         * RIGHT AILERON *                           $
CORD2R  110     0       26.7265 10.0    0.      26.7265 10.0    -10.0   +CRD2RA
+CRD2RA 36.7265 15.7735 0.
$                         * LEFT AILERON *                            $
CORD2R  210     0       26.7265 -10.0   0.      26.7265 -10.0   10.0    +CRD2LA
+CRD2LA 36.7265 -15.7735 0.
$                             * RUDDER *                              $
CORD2R  301     0       32.5    0.      0.      32.5    -10.    0.0     +CRD2R
+CRD2R  22.5    0.      5.7735
$       MID     E       G       NU      RHO     A       TREF    GE
MAT1    2       1.44+9  5.40+8          38.49002                        +MT2
$+MAT1  ST      SC      SS      MCSID
+MT2    7.20+6  5.76+6
MAT1    3       1.44+9  5.40+8          5.773503                        +MT3
+MT3    7.20+6  5.76+6
$       CID     CS      A1      A2      A3      B1      B2      B3
CORD2R  2       0       30.     0.      0.      30.     0.      10.     +CRD2RW
$       C1      C2      C3
+CRD2RW 38.66025+5.0    0.
$                         * LEFT WING SPLINE AXIS *                   $
$       CID     CS      A1      A2      A3      B1      B2      B3
CORD2R  20      0       30.     0.      0.      30.     0.      10.     +CRD2LW
$       C1      C2      C3
+CRD2LW 38.66025-5.0    0.
$                          * FIN SPLINE AXIS *                        $
CORD2R  300     0       30.0    0.      0.      30.0    10.0    0.      +CRD2FI
+CRD2FI 20.0    0.0     5.7735
$EIGR   SID     METHOD  F1      F2              NO                      +EIGR
$EIGR    20      AGIV                            15                      +AGIV
$       NORM    G       C                                               $
$+AGIV   MAX
EIGRL,20,,,15 $ MODERNIZE
PARAM   OPPHIPA 1
PARAM,LMODES,  12 $ END OF ha145ss8.cmn
```

The main Bulk Data Section includes the conventional data, plus GRID entries that list the points to which the engine links are attached. These points are connected to the wing grid points with rigid elements. The conventional aircraft model is described in this *MSC NASTRAN Aeroelastic Analysis User's Guide*, and is broken into part superelements. SEBULK entries are used to state that the external superelements are numbered 3 and 4. SECONCT entries are required to attach the generalized coordinates of part superelements 3 and 4 (the external superelements) to scalar points in the residual structure.

The external superelement geometry is described in part superelement files 3 and 4, which start with the delimiters BEGIN SUPER=[SEID]. PARAM, FIRSTKI, 161 lists the location of the first k-set point of the CAEROi point of superelement 3 in the internal sequence. PARAM, FIRSTKI, 201 lists the location of the first k-set point of the CAEROi point of superelement 4. The internal sequence of the k-set DOFs is a closed set, starting with the value of 1. The lowest-numbered CAEROi entry uses the first internal number, followed by a set of numbers in the range NSPAN*NCHORD-1 for the remaining points defined on that CAEROi entry. The next lowest-numbered CAEROi entry starts with the next internal number. As it is easy to miscalculate this number, a table correlating the external (CAEROi ID, etc.) vs. internal sequence of the k-set is printed at the beginning of the run, and has the appearance:

Listing 8-54 Correlation of User-input IDs of Aero Points with Internal Sequence Numbers

```
 U S E T   D E F I N I T I O N   T A B L E   ( I N T E R N A L   S E Q U E N C E ,   R O W   S O R T )
0
                                                         K        DISPLACEMENT SET
0             -1-         -2-         -3-         -4-         -5-         -6-         -7-         -8-         -9-        -10-

      1=     1000-3      1000-5      1001-3      1001-5      1002-3      1002-5      1003-3      1003-5      1004-3      1004-5      =    10
     11=     1005-3      1005-5      1006-3      1006-5      1007-3      1007-5      1100-3      1100-5      1101-3      1101-5      =    20
     21=     1102-3      1102-5      1103-3      1103-5      1104-3      1104-5      1105-3      1105-5      1106-3      1106-5      =    30
     31=     1107-3      1107-5      1108-3      1108-5      1109-3      1109-5      1110-3      1110-5      1111-3      1111-5      =    40
     41=     1112-3      1112-5      1113-3      1113-5      1114-3      1114-5      1115-3      1115-5      1116-3      1116-5      =    50
     51=     1117-3      1117-5      1118-3      1118-5      1119-3      1119-5      1120-3      1120-5      1121-3      1121-5      =    60
     61=     1122-3      1122-5      1123-3      1123-5      1124-3      1124-5      1125-3      1125-5      1126-3      1126-5      =    70
     71=     1127-3      1127-5      1128-3      1128-5      1129-3      1129-5      1130-3      1130-5      1131-3      1131-5      =    80
     81=     2000-3      2000-5      2001-3      2001-5      2002-3      2002-5      2003-3      2003-5      2004-3      2004-5      =    90
     91=     2005-3      2005-5      2006-3      2006-5      2007-3      2007-5      2100-3      2100-5      2101-3      2101-5      =   100
    101=     2102-3      2102-5      2103-3      2103-5      2104-3      2104-5      2105-3      2105-5      2106-3      2106-5      =   110
    111=     2107-3      2107-5      2108-3      2108-5      2109-3      2109-5      2110-3      2110-5      2111-3      2111-5      =   120
    121=     2112-3      2112-5      2113-3      2113-5      2114-3      2114-5      2115-3      2115-5      2116-3      2116-5      =   130
    131=     2117-3      2117-5      2118-3      2118-5      2119-3      2119-5      2120-3      2120-5      2121-3      2121-5      =   140
    141=     2122-3      2122-5      2123-3      2123-5      2124-3      2124-5      2125-3      2125-5      2126-3      2126-5      =   150
    151=     2127-3      2127-5      2128-3      2128-5      2129-3      2129-5      2130-3      2130-5      2131-3      2131-5      =   160
    161=     3001-3      3001-5      3002-3      3002-5      3003-3      3003-5      3004-3      3004-5      3100-3      3100-5      =   170
    171=     3101-3      3101-5      3102-3      3102-5      3103-3      3103-5      3104-3      3104-5      3105-3      3105-5      =   180
    181=     3106-3      3106-5      3107-3      3107-5      3108-3      3108-5      3109-3      3109-5      3110-3      3110-5      =   190
    191=     3111-3      3111-5      3112-3      3112-5      3113-3      3113-5      3114-3      3114-5      3115-3      3115-5      =   200
    201=     4001-3      4001-5      4002-3      4002-5      4003-3      4003-5      4004-3      4004-5
```

It is essential that the FIRSTKI values be input correctly because they are used to make a partitioning vector that inserts the spline matrices for the external superelements in the proper columns. Some checks for necessary but not sufficient attributes are made to determine that the columns have been inserted properly. One such check is for the presence of null columns in the total assembled spline matrix. All null columns are identified in terms of their k-set index. While null columns may be permissible in some circumstances, they are usually an indication of a modelling error, and should be checked out. A corollary of this discussion is that if the external superelement has more than one CAEROi entry their Ids must be numbered such that they are adjacent to each other in the sorted sequence of the assembly input file. Also note that all CAEROi entries are placed in the same interference group to couple their aerodynamic effects.

PARAM, EXTDROUT, MATRIXDB selects the database-matrix option for obtaining the boundary matrices. The EXTRN entry lists the boundary points and their connected DOFs, including the generalized coordinates. The grid points and generalized coordinates of the external superelement are entered here. The grid points are located relative to a local coordinate system which moves the centerline plane of the engine to the wing tip. This is the same coordinate system used to locate the CAEROi entry. No ASETi entries are used so that all DOFs in the part file remain in its a-set.

The CAEROi-type data for the external superelements is copied from the set used for the engine reduction run, except that a coordinate system is referenced which aligns the CAEROi entry with the engine mount points. Portions of results for the Assembly run can be seen in Listing 8-55 below.

Listing 8-55 Portions of Results of Assembly Run for Example HA145SS8

```
1    EXAMPLE HA200A: 30 DEG FWD SWEPT WING WITH CANARD      HA145SS8        AUGUST  17, 2021  MSC Nastran  8/16/21    PAGE    39
0     SUBSONIC FLUTTER ANALYSIS
                                             M O D E L   S U M M A R Y            BULK = 0
                                        ENTRY NAME         NUMBER OF ENTRIES
                                        ----------         -----------------
                                              AERO                         1
                                            CAERO1                         7
                                              CBAR                         9
                                             CONM2                         8
                                            CORD2R                        11
                                             EIGRL                         1
                                            FLFACT                         6
                                           FLUTTER                         2
                                              GRID                        29
                                              MAT1                         4
                                           MKAERO1                         1
                                            PAERO1                         1
                                             PARAM                         5
                                              PBAR                         5
                                            PLOTEL                        16
                                              RBAR                         8
                                              RBE2                         4
                                            SEBULK                         2
                                           SECONCT                         2
                                           SENQSET                         2
                                              SET1                         3
                                           SPLINE2                         4
                                            SPOINT                        40
                                            SUPORT                         1

                                             M O D E L   S U M M A R Y            SUPER = 3
                                        ENTRY NAME         NUMBER OF ENTRIES
                                        ----------         -----------------
                                              AERO                         1
                                            CAERO1                         7
                                            CORD2R                        10
                                             EIGRL                         1
                                             EXTRN                         1
                                              GRID                         4
                                              MAT1                         3
                                           MKAERO1                         1
                                            PAERO1                         1
                                             PARAM                         6
                                              PBAR                         2
                                            SPOINT                        20
 M O D E L   S U M M A R Y              SUPER = 4
                                        ENTRY NAME         NUMBER OF ENTRIES
                                        ----------         -----------------
                                              AERO                         1
                                            CAERO1                         7
                                            CORD2R                        10
                                             EIGRL                         1
                                             EXTRN                         1
                                              GRID                         4
                                              MAT1                         3
                                           MKAERO1                         1
                                            PAERO1                         1
                                             PARAM                         6
                                              PBAR                         2
                                            SPOINT                        20

                                             M O D E L   S U M M A R Y            SUPER = 10
                                        ENTRY NAME         NUMBER OF ENTRIES
                                        ----------         -----------------
                                              AERO                         1
                                            CAERO1                         7
                                              CBAR                         4
                                             CONM2                         4
                                            CORD2R                        10
                                             EIGRL                         1
                                              GRID                         5
                                              MAT1                         3
                                           MKAERO1                         1
                                            PAERO1                         1
                                             PARAM                         5
                                              PBAR                         2
                                              SET1                         1
                                           SPLINE2                         2
```

Listing 8-55 Portions of Results of Assembly Run for Example HA145SS8 (Continued)

```
 M O D E L   S U M M A R Y          SUPER = 20
                                   ENTRY NAME        NUMBER OF ENTRIES
                                   ----------        -----------------
                                         AERO                        1
                                       CAERO1                        7
                                         CBAR                        1
                                        CONM2                        2
                                       CORD2R                       10
                                        EIGRL                        1
                                         GRID                        5
                                         MAT1                        3
                                      MKAERO1                        1
                                       PAERO1                        1
                                        PARAM                        5
                                         PBAR                        2
                                       PLOTEL                        2
                                         RBAR                        2
                                         SET1                        1
                                      SPLINE2                        1

 ^^^
 ^^^ >>> IFP OPERATIONS COMPLETE <<<
 ^^^
1    EXAMPLE HA200A: 30 DEG FWD SWEPT WING WITH CANARD      HA145SS8         AUGUST  17, 2021  MSC Nastran  8/16/21   PAGE    42

0     SUBSONIC FLUTTER ANALYSIS

0                                           SUPERELEMENT DEFINITION TABLE (SORTED BY SEID)
0                 PRIMARY    PROCESS  DOWNSTREAM
 SUPERELEMENT SUPERELEMENT  ORDER  SUPERELEMENT           TYPE                                     LABEL
 ------------ ------------ ------- ------------ -----------------------------  ------------------------------------------------
        0            0        5          0    RESIDUAL STRUCTURE
        3            3        1          0    EXTERNAL (SEBULK (A-SET))
        4            4        2          0    EXTERNAL (SEBULK (A-SET))
       10            0        3          0    PRIMARY (BEGIN SUPER)
       20            0        4          0    PRIMARY (BEGIN SUPER)

0                                           SUPERELEMENT DEFINITION TABLE (SORTED BY PROCESS ORDER)
0                 PRIMARY    PROCESS  DOWNSTREAM
 SUPERELEMENT SUPERELEMENT  ORDER  SUPERELEMENT           TYPE                                     LABEL
 ------------ ------------ ------- ------------ -----------------------------  ------------------------------------------------
        3            3        1          0    EXTERNAL (SEBULK (A-SET))
        4            4        2          0    EXTERNAL (SEBULK (A-SET))
       10            0        3          0    PRIMARY (BEGIN SUPER)
       20            0        4          0    PRIMARY (BEGIN SUPER)
        0            0        5          0    RESIDUAL STRUCTURE
0
                               TABLE OF DOWNSTREAM SUPERELEMENTS FOR EACH SUPERELEMENT
0 SUPERELEMENT                       DOWNSTREAM SUPERELEMENTS IN DOWNSTREAM ORDER
  ------------  --------------------------------------------------------------------------------
          3           0
          4           0
         10           0
         20           0
1    EXAMPLE HA200A: 30 DEG FWD SWEPT WING WITH CANARD      HA145SS8         AUGUST  17, 2021  MSC Nastran  8/16/21   PAGE    43

0     SUBSONIC FLUTTER ANALYSIS
0                                                S U P E R E L E M E N T   T R E E
0                                   ( CONFIGURATION = SINGLE LEVEL   NO. LEVELS =  1     NO. TIPS =   4 )
0   TIP      LEVEL      LEVEL      LEVEL      LEVEL      LEVEL      LEVEL      LEVEL      LEVEL      LEVEL      LEVEL      LEVEL      LEVEL
   INDEX      -1-        -2-        -3-        -4-        -5-        -6-        -7-        -8-        -9-       -10-       -11-       -12-
      1         3
      2         4
      3        10
      4        20

...
...
...
```

Listing 8-55 Portions of Results of Assembly Run for Example HA145SS8 (Continued)

```
1    EXAMPLE HA200A: 30 DEG FWD SWEPT WING WITH CANARD      HA145SS8        AUGUST  17, 2021  MSC Nastran  8/16/21   PAGE    44
0     SUBSONIC FLUTTER ANALYSIS
0                      POINT/SUPERELEMENT CONNECTIVITY LIST (SORTED BY FIRST POINT ID - "B" INDICATES BOUNDARY SEQUENCE ID)
0              FIRST           INTERIOR TO
     COUNT   POINT ID  TYPE  SUPERELEMEMT ------------------------------- CONNECTED TO SUPERELEMENT ----------------------------
---

        24        1B              0          3
        24       26B              0          4
         2       51B              0         10
         2       53B              0         10       20
1    EXAMPLE HA200A: 30 DEG FWD SWEPT WING WITH CANARD      HA145SS8        AUGUST  17, 2021  MSC Nastran  8/16/21   PAGE    47

0     SUBSONIC FLUTTER ANALYSIS
0                      POINT/SUPERELEMENT CONNECTIVITY LIST (SORTED BY COUNT - "B" INDICATES BOUNDARY SEQUENCE ID)
0              FIRST           INTERIOR TO
     COUNT   POINT ID  TYPE  SUPERELEMEMT ------------------------------- CONNECTED TO SUPERELEMENT ----------------------------
---

         2       53B              0         10       20
         2       51B              0         10
        24        1B              0          3
        24       26B              0          4
1    EXAMPLE HA200A: 30 DEG FWD SWEPT WING WITH CANARD      HA145SS8        AUGUST  17, 2021  MSC Nastran  8/16/21   PAGE    48

0     SUBSONIC FLUTTER ANALYSIS
0                     POINT/SUPERELEMENT CONNECTIVITY LIST (SORTED BY INTERIOR SUPERELEMENT - "B" INDICATES BOUNDARY SEQUENCE ID)
0              FIRST           INTERIOR TO
     COUNT   POINT ID  TYPE  SUPERELEMEMT ------------------------------- CONNECTED TO SUPERELEMENT ----------------------------
---

         2       53B              0         10       20
        24        1B              0          3
         2       51B              0         10
        24       26B              0          4
1    EXAMPLE HA200A: 30 DEG FWD SWEPT WING WITH CANARD      HA145SS8        AUGUST  17, 2021  MSC Nastran  8/16/21   PAGE    49

0     SUBSONIC FLUTTER ANALYSIS

0                                            SUPERELEMENT       0
        TYPE = RESIDUAL STRUCTURE
                                          LIST OF  INTERIOR POINTS         ( TOTAL NO. OF INTERIOR POINT =       52 )
     INDEX          -1-         -2-         -3-         -4-         -5-         -6-         -7-         -8-         -9-        -10-
       1             1B          2B          3B          4B          5B          6B          7B          8B          9B         10B
      11            11B         12B         13B         14B         15B         16B         17B         18B         19B         20B
      21            21B         22B         23B         25B         26B         27B         28B         29B         30B         31B
      31            32B         33B         34B         35B         36B         37B         38B         39B         40B         41B
      41            42B         43B         44B         45B         46B         47B         48B         50B         51B         52B
      51            53B         54B

0                                            SUPERELEMENT       0
        TYPE = RESIDUAL STRUCTURE
                                          LIST OF  ELEMENTS               ( TOTAL NO. OF ELEMENTS      =       45 )
     INDEX          -1-         -2-         -3-         -4-         -5-         -6-         -7-         -8-         -9-        -10-
       1              1           2           3           4           5         110         111         112         120         121
      11            122         210         211         212         220         221         222        1110        1120        1130
      21           1140        1210        1220        2110        2120        2210        2220        9111        9112        9121
      31           9122        9211        9212        9221        9222       91110       91111       91112       91113       91114
      41          91120       91121       91122       91123       91124

0                                            SUPERELEMENT       3
        TYPE = EXTERNAL (SEBULK (A-SET))
                                          LIST OF  EXTERIOR POINTS         ( TOTAL NO. OF EXTERIOR POINT =       24 )
     INDEX          -1-         -2-         -3-         -4-         -5-         -6-         -7-         -8-         -9-        -10-
       1             1B          2B          3B          4B          5B          6B          7B          8B          9B         10B
      11            11B         12B         13B         14B         15B         16B         17B         18B         19B         20B
      21            21B         22B         23B         25B

0                                            SUPERELEMENT       4
        TYPE = EXTERNAL (SEBULK (A-SET))
                                          LIST OF  EXTERIOR POINTS         ( TOTAL NO. OF EXTERIOR POINT =       24 )
     INDEX          -1-         -2-         -3-         -4-         -5-         -6-         -7-         -8-         -9-        -10-
       1            26B         27B         28B         29B         30B         31B         32B         33B         34B         35B
      11            36B         37B         38B         39B         40B         41B         42B         43B         44B         45B
      21            46B         47B         48B         50B
```

Listing 8-55 Portions of Results of Assembly Run for Example HA145SS8 (Continued)

```
0                                          SUPERELEMENT      10
        TYPE = PRIMARY (BEGIN SUPER)
                                        LIST OF  EXTERIOR POINTS         ( TOTAL NO. OF EXTERIOR POINT =        4 )
     INDEX          -1-          -2-          -3-          -4-          -5-          -6-          -7-          -8-          -9-          -10-
        1           51B          52B          53B          54B

0                                          SUPERELEMENT      20
        TYPE = PRIMARY (BEGIN SUPER)
                                        LIST OF  EXTERIOR POINTS         ( TOTAL NO. OF EXTERIOR POINT =        2 )
     INDEX          -1-          -2-          -3-          -4-          -5-          -6-          -7-          -8-          -9-          -10-
        1           53B          54B

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1    EXAMPLE HA200A: 30 DEG FWD SWEPT WING WITH CANARD      HA145SS8        AUGUST  17, 2021  MSC Nastran  8/16/21   PAGE    70
0     SUBSONIC FLUTTER ANALYSIS

                                           R E A L   E I G E N V A L U E S
                                     (BEFORE AUGMENTATION OF RESIDUAL VECTORS)
   MODE    EXTRACTION      EIGENVALUE            RADIANS             CYCLES            GENERALIZED         GENERALIZED
    NO.       ORDER                                                                       MASS              STIFFNESS
        1         1        1.379851E+06        1.174670E+03        1.869546E+02        1.000000E+00        1.379851E+06
        2         2        5.874954E+06        2.423830E+03        3.857646E+02        1.000000E+00        5.874954E+06
        3         3        1.987639E+07        4.458295E+03        7.095597E+02        1.000000E+00        1.987639E+07
        4         4        2.169934E+07        4.658255E+03        7.413843E+02        1.000000E+00        2.169934E+07
        5         5        1.641800E+08        1.281327E+04        2.039296E+03        1.000000E+00        1.641800E+08

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1    EXAMPLE HA200A: 30 DEG FWD SWEPT WING WITH CANARD      HA145SS8        AUGUST  17, 2021  MSC Nastran  8/16/21   PAGE    99
0     SUBSONIC FLUTTER ANALYSIS
0

                      E I G E N V A L U E   A N A L Y S I S   S U M M A R Y   (READ MODULE)


                                   BLOCK SIZE USED ......................     7

                                   NUMBER OF DECOMPOSITIONS ............     2

                                   NUMBER OF ROOTS FOUND ...............    15

                                   NUMBER OF SOLVES REQUIRED ...........     7

...
...
...
1    EXAMPLE HA200A: 30 DEG FWD SWEPT WING WITH CANARD      HA145SS8        AUGUST  17, 2021  MSC Nastran  8/16/21   PAGE   102
0     SUBSONIC FLUTTER ANALYSIS

                                           R E A L   E I G E N V A L U E S
                                    (ACTUAL MODES USED IN THE DYNAMIC ANALYSIS)
   MODE    EXTRACTION      EIGENVALUE            RADIANS             CYCLES            GENERALIZED         GENERALIZED
    NO.       ORDER                                                                       MASS              STIFFNESS
        1         1        0.0                 0.0                 0.0                 1.000000E+00        0.0
        2         2        0.0                 0.0                 0.0                 1.000000E+00        0.0
        3         3        0.0                 0.0                 0.0                 1.000000E+00        0.0
        4         4        0.0                 0.0                 0.0                 1.000000E+00        0.0
        5         5        0.0                 0.0                 0.0                 1.000000E+00        0.0
        6         6        0.0                 0.0                 0.0                 1.000000E+00        0.0
        7         7        2.008328E+03        4.481437E+01        7.132429E+00        1.000000E+00        2.008328E+03
        8         8        3.340276E+03        5.779512E+01        9.198379E+00        1.000000E+00        3.340276E+03
        9         9        1.280488E+04        1.131586E+02        1.800976E+01        1.000000E+00        1.280488E+04
       10        10        2.054010E+04        1.433182E+02        2.280980E+01        1.000000E+00        2.054010E+04
       11        11        4.150488E+04        2.037275E+02        3.242423E+01        1.000000E+00        4.150488E+04
       12        12        5.314543E+04        2.305329E+02        3.669046E+01        1.000000E+00        5.314543E+04
1    EXAMPLE HA200A: 30 DEG FWD SWEPT WING WITH CANARD      HA145SS8        AUGUST  17, 2021  MSC Nastran  8/16/21   PAGE   103
                                                                                                        SUPERELEMENT 0
0     SUBSONIC FLUTTER ANALYSIS
      EIGENVALUE =  0.000000E+00
          CYCLES =  0.000000E+00         R E A L   E I G E N V E C T O R   N O .         1
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Listing 8-55 Portions of Results of Assembly Run for Example HA145SS8 (Continued)

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 POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
          1      G     -1.672180E-04   5.297502E-02  -7.058013E-04  -7.240876E-03   4.663396E-05  -5.962572E-05
          2      G      4.652083E-04   5.234260E-02  -7.800151E-02  -7.240876E-03   4.663396E-05  -5.962572E-05
          3      G      4.652083E-04   5.360745E-02  -7.701226E-02  -7.240876E-03   4.663396E-05  -5.962572E-05
          4      G     -7.996443E-04   5.360745E-02   7.658991E-02  -7.240876E-03   4.663396E-05  -5.962572E-05
          5      G     -7.996443E-04   5.234260E-02   7.560066E-02  -7.240876E-03   4.663396E-05  -5.962572E-05
         11      G     -1.447667E-03   2.060054E-03   1.149692E-01  -7.240876E-03   4.663396E-05  -5.962572E-05
         12      G      3.411044E-04   2.060054E-03  -1.022570E-01  -7.240876E-03   4.663396E-05  -5.962572E-05
         13      G     -1.328416E-03   2.060054E-03   1.004875E-01  -7.240876E-03   4.663396E-05  -5.962572E-05
         14      G      4.603558E-04   2.060054E-03  -1.167388E-01  -7.240876E-03   4.663396E-05  -5.962572E-05
         21      G     -1.447667E-03   1.761925E-03   1.147361E-01  -7.240876E-03   4.663396E-05  -5.962572E-05
         22      G      3.411044E-04   1.761925E-03  -1.024902E-01  -7.240876E-03   4.663396E-05  -5.962572E-05
         23      G     -1.328416E-03   1.761925E-03   1.002543E-01  -7.240876E-03   4.663396E-05  -5.962572E-05
         24      G      4.603558E-04   1.761925E-03  -1.169720E-01  -7.240876E-03   4.663396E-05  -5.962572E-05
         90      G     -4.936558E-04   2.288895E-03  -7.058013E-04  -7.240876E-03   4.663396E-05  -5.962572E-05
         98      G     -4.936558E-04   2.587023E-03  -4.726315E-04  -7.240876E-03   4.663396E-05  -5.962572E-05
         99      G     -4.936558E-04   1.990766E-03  -9.389711E-04  -7.240876E-03   4.663396E-05  -5.962572E-05
        100      G     -4.936558E-04   1.394509E-03  -1.405311E-03  -7.240876E-03   4.663396E-05  -5.962572E-05
        110      G     -1.955271E-04   1.566633E-03  -3.747507E-02  -7.240876E-03   4.663396E-05  -5.962572E-05
        111      G     -1.955271E-04   1.715698E-03  -3.735848E-02  -7.240876E-03   4.663396E-05  -5.962572E-05
        112      G     -1.955271E-04   1.417569E-03  -3.759165E-02  -7.240876E-03   4.663396E-05  -5.962572E-05
        120      G      4.007301E-04   1.910882E-03  -1.096146E-01  -7.240876E-03   4.663396E-05  -5.962572E-05
        121      G      4.007301E-04   2.059947E-03  -1.094980E-01  -7.240876E-03   4.663396E-05  -5.962572E-05
        122      G      4.007301E-04   1.761818E-03  -1.097312E-01  -7.240876E-03   4.663396E-05  -5.962572E-05
        210      G     -7.917844E-04   1.566633E-03   3.493369E-02  -7.240876E-03   4.663396E-05  -5.962572E-05
        211      G     -7.917844E-04   1.715698E-03   3.505027E-02  -7.240876E-03   4.663396E-05  -5.962572E-05
        212      G     -7.917844E-04   1.417569E-03   3.481710E-02  -7.240876E-03   4.663396E-05  -5.962572E-05
        220      G     -1.388042E-03   1.910882E-03   1.076117E-01  -7.240876E-03   4.663396E-05  -5.962572E-05
        221      G     -1.388042E-03   2.059947E-03   1.077283E-01  -7.240876E-03   4.663396E-05  -5.962572E-05
        222      G     -1.388042E-03   1.761818E-03   1.074951E-01  -7.240876E-03   4.663396E-05  -5.962572E-05
        701      S     -8.659757E-20   6.119836E-17  -5.558045E-18  -3.246794E-19  -1.721306E-19  -1.955512E-19
        707      S      3.058398E-22  -1.274540E-19  -1.276501E-19   0.0           -5.251882E-18   5.101889E-20
        713      S      6.689779E-22  -2.334248E-22  -6.101935E-22  -1.167646E-22  -6.116725E-21   1.891843E-22
        719      S     -1.189796E-22   0.0           -4.100569E-19  -6.015310E-17  -6.751580E-18  -2.362637E-19
        725      S      1.041663E-18   5.331019E-19   4.317971E-20  -1.226998E-19  -1.179533E-19   0.0
        731      S     -1.274033E-18   2.200594E-20   1.897017E-21  -1.165428E-22   7.837320E-22  -5.423040E-22
        737      S      5.923325E-21   5.687739E-22  -4.607801E-22   0.0
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1    EXAMPLE HA200A: 30 DEG FWD SWEPT WING WITH CANARD      HA145SS8        AUGUST  17, 2021  MSC Nastran  8/16/21    PAGE   120
0     SUBSONIC FLUTTER ANALYSIS
      EIGENVALUE =  0.000000E+00
          CYCLES =  0.000000E+00         R E A L   E I G E N V E C T O R   N O .          1

      POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
          1000      G      0.0            0.0           -1.916404E-02   0.0            9.326793E-05   0.0
          1001      G      0.0            0.0           -1.939721E-02   0.0            9.326793E-05   0.0
          1002      G      0.0            0.0           -1.963038E-02   0.0            9.326793E-05   0.0
          1003      G      0.0            0.0           -1.986355E-02   0.0            9.326793E-05   0.0
          1004      G      0.0            0.0           -5.536842E-02   0.0            9.326793E-05   0.0
          1005      G      0.0            0.0           -5.560159E-02   0.0            9.326793E-05   0.0
          1006      G      0.0            0.0           -5.583476E-02   0.0            9.326793E-05   0.0
          1007      G      0.0            0.0           -5.606792E-02   0.0            9.326793E-05   0.0
          1100      G      0.0            0.0           -1.024787E-02   0.0            4.663396E-05   0.0
          1101      G      0.0            0.0           -1.036446E-02   0.0            4.663396E-05   0.0
          1102      G      0.0            0.0           -1.048104E-02   0.0            4.663396E-05   0.0
          1103      G      0.0            0.0           -1.059763E-02   0.0            4.663396E-05   0.0
          1104      G      0.0            0.0           -2.828275E-02   0.0            4.663396E-05   0.0
          1105      G      0.0            0.0           -2.839934E-02   0.0            4.663396E-05   0.0
          1106      G      0.0            0.0           -2.851592E-02   0.0            4.663396E-05   0.0
          1107      G      0.0            0.0           -2.863251E-02   0.0            4.663396E-05   0.0
          1108      G      0.0            0.0           -4.631763E-02   0.0            4.663396E-05   0.0
          1109      G      0.0            0.0           -4.643422E-02   0.0            4.663396E-05   0.0
          1110      G      0.0            0.0           -4.655080E-02   0.0            4.663396E-05   0.0
          1111      G      0.0            0.0           -4.666739E-02   0.0            4.663396E-05   0.0
          1112      G      0.0            0.0           -6.435251E-02   0.0            4.663396E-05   0.0
          1113      G      0.0            0.0           -6.446909E-02   0.0            4.663396E-05   0.0
          1114      G      0.0            0.0           -6.458568E-02   0.0            4.663396E-05   0.0
          1115      G      0.0            0.0           -6.470226E-02   0.0            4.663396E-05   0.0
          1116      G      0.0            0.0           -8.238739E-02   0.0            4.663396E-05   0.0
          1117      G      0.0            0.0           -8.250397E-02   0.0            4.663396E-05   0.0
          1118      G      0.0            0.0           -8.262056E-02   0.0            4.663396E-05   0.0
          1119      G      0.0            0.0           -8.273714E-02   0.0            4.663396E-05   0.0
          1120      G      0.0            0.0           -1.004223E-01   0.0            4.663396E-05   0.0
          1121      G      0.0            0.0           -1.005389E-01   0.0            4.663396E-05   0.0
          1122      G      0.0            0.0           -1.006554E-01   0.0            4.663396E-05   0.0
          1123      G      0.0            0.0           -1.007720E-01   0.0            4.663396E-05   0.0
          1124      G      0.0            0.0           -1.184571E-01   0.0            4.663396E-05   0.0
          1125      G      0.0            0.0           -1.185737E-01   0.0            4.663396E-05   0.0
          1126      G      0.0            0.0           -1.186903E-01   0.0            4.663396E-05   0.0
          1127      G      0.0            0.0           -1.188069E-01   0.0            4.663396E-05   0.0
          1128      G      0.0            0.0           -1.364920E-01   0.0            4.663396E-05   0.0
          1129      G      0.0            0.0           -1.366086E-01   0.0            4.663396E-05   0.0
          1130      G      0.0            0.0           -1.367252E-01   0.0            4.663396E-05   0.0
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Listing 8-55 Portions of Results of Assembly Run for Example HA145SS8 (Continued)

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  1131      G     0.0           0.0          -1.368418E-01   0.0          4.663396E-05   0.0
          2000      G      0.0            0.0            5.324472E-02   0.0            9.326793E-05   0.0
          2001      G      0.0            0.0            5.301155E-02   0.0            9.326793E-05   0.0
          2002      G      0.0            0.0            5.277838E-02   0.0            9.326793E-05   0.0
          2003      G      0.0            0.0            5.254521E-02   0.0            9.326793E-05   0.0
          2004      G      0.0            0.0            1.704034E-02   0.0            9.326793E-05   0.0
          2005      G      0.0            0.0            1.680717E-02   0.0            9.326793E-05   0.0
          2006      G      0.0            0.0            1.657400E-02   0.0            9.326793E-05   0.0
          2007      G      0.0            0.0            1.634083E-02   0.0            9.326793E-05   0.0
          2100      G      0.0            0.0            1.350408E-01   0.0            4.663396E-05   0.0
          2101      G      0.0            0.0            1.349242E-01   0.0            4.663396E-05   0.0
      POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
          2102      G      0.0            0.0            1.348076E-01   0.0            4.663396E-05   0.0
          2103      G      0.0            0.0            1.346911E-01   0.0            4.663396E-05   0.0
          2104      G      0.0            0.0            1.168713E-01   0.0            4.663396E-05   0.0
          2105      G      0.0            0.0            1.167547E-01   0.0            4.663396E-05   0.0
          2106      G      0.0            0.0            1.166381E-01   0.0            4.663396E-05   0.0
          2107      G      0.0            0.0            1.165216E-01   0.0            4.663396E-05   0.0
          2108      G      0.0            0.0            9.870181E-02   0.0            4.663396E-05   0.0
          2109      G      0.0            0.0            9.858523E-02   0.0            4.663396E-05   0.0
          2110      G      0.0            0.0            9.846864E-02   0.0            4.663396E-05   0.0
          2111      G      0.0            0.0            9.835206E-02   0.0            4.663396E-05   0.0
          2112      G      0.0            0.0            8.053231E-02   0.0            4.663396E-05   0.0
          2113      G      0.0            0.0            8.041573E-02   0.0            4.663396E-05   0.0
          2114      G      0.0            0.0            8.029915E-02   0.0            4.663396E-05   0.0
          2115      G      0.0            0.0            8.018256E-02   0.0            4.663396E-05   0.0
          2116      G      0.0            0.0            6.236282E-02   0.0            4.663396E-05   0.0
          2117      G      0.0            0.0            6.224623E-02   0.0            4.663396E-05   0.0
          2118      G      0.0            0.0            6.212965E-02   0.0            4.663396E-05   0.0
          2119      G      0.0            0.0            6.201306E-02   0.0            4.663396E-05   0.0
          2120      G      0.0            0.0            4.419332E-02   0.0            4.663396E-05   0.0
          2121      G      0.0            0.0            4.407673E-02   0.0            4.663396E-05   0.0
          2122      G      0.0            0.0            4.396015E-02   0.0            4.663396E-05   0.0
          2123      G      0.0            0.0            4.384356E-02   0.0            4.663396E-05   0.0
          2124      G      0.0            0.0            2.602382E-02   0.0            4.663396E-05   0.0
          2125      G      0.0            0.0            2.590723E-02   0.0            4.663396E-05   0.0
          2126      G      0.0            0.0            2.579065E-02   0.0            4.663396E-05   0.0
          2127      G      0.0            0.0            2.567406E-02   0.0            4.663396E-05   0.0
          2128      G      0.0            0.0            7.854316E-03   0.0            4.663396E-05   0.0
          2129      G      0.0            0.0            7.737732E-03   0.0            4.663396E-05   0.0
          2130      G      0.0            0.0            7.621147E-03   0.0            4.663396E-05   0.0
          2131      G      0.0            0.0            7.504562E-03   0.0            4.663396E-05   0.0
          3001      G      0.0            0.0           -1.276584E-01   0.0            4.663396E-05   0.0
          3002      G      0.0            0.0           -1.277750E-01   0.0            4.663396E-05   0.0
          3003      G      0.0            0.0           -1.348993E-01   0.0            4.663396E-05   0.0
          3004      G      0.0            0.0           -1.350159E-01   0.0            4.663396E-05   0.0
          3100      G      0.0            0.0            6.467455E-02   0.0            5.962572E-05   0.0
          3101      G      0.0            0.0            6.452549E-02   0.0            5.962572E-05   0.0
          3102      G      0.0            0.0            6.437642E-02   0.0            5.962572E-05   0.0
          3103      G      0.0            0.0            6.422736E-02   0.0            5.962572E-05   0.0
          3104      G      0.0            0.0            4.665842E-02   0.0            5.962572E-05   0.0
          3105      G      0.0            0.0            4.650936E-02   0.0            5.962572E-05   0.0
          3106      G      0.0            0.0            4.636029E-02   0.0            5.962572E-05   0.0
          3107      G      0.0            0.0            4.621123E-02   0.0            5.962572E-05   0.0
          3108      G      0.0            0.0            2.864230E-02   0.0            5.962572E-05   0.0
          3109      G      0.0            0.0            2.849323E-02   0.0            5.962572E-05   0.0
          3110      G      0.0            0.0            2.834417E-02   0.0            5.962572E-05   0.0
          3111      G      0.0            0.0            2.819510E-02   0.0            5.962572E-05   0.0
          3112      G      0.0            0.0            1.062617E-02   0.0            5.962572E-05   0.0
          3113      G      0.0            0.0            1.047710E-02   0.0            5.962572E-05   0.0
          3114      G      0.0            0.0            1.032804E-02   0.0            5.962572E-05   0.0
          3115      G      0.0            0.0            1.017898E-02   0.0            5.962572E-05   0.0
      POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
          4001      G      0.0            0.0            8.956787E-02   0.0            4.663396E-05   0.0
          4002      G      0.0            0.0            8.945129E-02   0.0            4.663396E-05   0.0
          4003      G      0.0            0.0            8.232700E-02   0.0            4.663396E-05   0.0
          4004      G      0.0            0.0            8.221041E-02   0.0            4.663396E-05   0.0

...
...
...
```

Listing 8-55 Portions of Results of Assembly Run for Example HA145SS8 (Continued)

```
 A ZERO FREQUENCY ROOT HAS EMERGED.  WHEN THE MACH NO., DENSITY AND VELOCITY ARE COMPATIBLE
 IT MAY BE INTERPRETED TWO WAYS DEPENDING ON THE SIGN OF THE REAL PART:
   1. (-) A MODE IS CRITICALLY DAMPED, OR,
   2. (+) THE SYSTEM IS DIVERGING.
 ONLY THE MOST CRITICAL ( I.E., MOST POSITIVE REAL ROOTS )  ARE PRINTED IN THE FLUTTER SUMMARY.
 FOR INFORMATIONAL PURPOSES, THE REMAINING REAL ROOTS ARE PRINTED HERE.

      LESS CRITICAL REAL ROOTS FOR LOOP    1       MACH        VELOCITY        DENSITY
                                              9.00000E-01    1.00000E+03    1.00000E+00

         KFREQ          DAMPING                COMPLEX EIGENVALUE

        0.0000     -1.9162689E-03       1.8693857E-05       -1.9510682E-02
        0.0000     -1.2954974E-01      -8.9796108E+00        0.0000000E+00
        0.0000     -8.3821326E-06      -5.8099914E-04        0.0000000E+00
        0.0000     -1.4293081E-08      -9.9071064E-07        0.0000000E+00

 ...
 ...
 ...
      LESS CRITICAL REAL ROOTS FOR LOOP    7       MACH        VELOCITY        DENSITY
                                              9.00000E-01    1.60000E+03    1.00000E+00

         KFREQ          DAMPING                COMPLEX EIGENVALUE

        0.0000     -3.7638022E-04       3.6870745E-06       -1.9592286E-02
        0.0000     -1.4107587E-01      -1.5645653E+01        0.0000000E+00
        0.0000     -8.4002423E-06      -9.3160703E-04        0.0000000E+00
        0.0000     -2.4167763E-08      -2.6802629E-06        0.0000000E+00
1    EXAMPLE HA200A: 30 DEG FWD SWEPT WING WITH CANARD      HA145SS8         AUGUST  17, 2021  MSC Nastran  8/16/21   PAGE   172
0     SUBSONIC FLUTTER ANALYSIS
0                                                        FLUTTER  SUMMARY
                       CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = ASYMMETRIC
       POINT =     1     MACH NUMBER =  0.9000     DENSITY RATIO =  1.0000E+00     METHOD = PK

       KFREQ           1./KFREQ         VELOCITY           DAMPING         FREQUENCY           COMPLEX   EIGENVALUE
        0.0000       1.0000000E+25     1.0000000E+03    -3.7725404E-09     0.0000000E+00    -2.6148986E-07     0.0000000E+00
        0.0000       1.0000000E+25     1.1000000E+03    -6.3381911E-10     0.0000000E+00    -4.8325792E-08     0.0000000E+00
        0.0000       1.0000000E+25     1.2000000E+03     1.4036874E-09     0.0000000E+00     1.1675423E-07     0.0000000E+00
        0.0000       1.0000000E+25     1.3000000E+03     5.5289500E-10     0.0000000E+00     4.9820373E-08     0.0000000E+00
        0.0000       1.0000000E+25     1.4000000E+03    -3.6619329E-10     0.0000000E+00    -3.5535251E-08     0.0000000E+00
        0.0000       1.0000000E+25     1.5000000E+03    -2.2894396E-10     0.0000000E+00    -2.3803533E-08     0.0000000E+00
        0.0000       1.0000000E+25     1.6000000E+03    -4.2898697E-10     0.0000000E+00    -4.7575684E-08     0.0000000E+00

 ...
 ...
 ...
0                                                        FLUTTER  SUMMARY
                       CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = ASYMMETRIC
       POINT =     8     MACH NUMBER =  0.9000     DENSITY RATIO =  1.0000E+00     METHOD = PK

       KFREQ           1./KFREQ         VELOCITY           DAMPING         FREQUENCY           COMPLEX   EIGENVALUE
        0.2440       4.0990023E+00     1.0000000E+03    -1.6918875E-01     7.7655454E+00    -4.1275592E+00     4.8792360E+01
        0.2086       4.7947709E+00     1.1000000E+03    -2.0847257E-01     7.3025570E+00    -4.7827066E+00     4.5883319E+01
        0.1741       5.7451700E+00     1.2000000E+03    -2.5024382E-01     6.6485737E+00    -5.2268702E+00     4.1774221E+01
        0.1352       7.3938161E+00     1.3000000E+03    -2.4104164E-01     5.5966073E+00    -4.2380570E+00     3.5164521E+01
        0.1099       9.1015008E+00     1.4000000E+03     1.2903107E-01     4.8962677E+00     1.9847661E+00     3.0764157E+01
        0.1003       9.9709615E+00     1.5000000E+03     4.3597860E-01     4.7885535E+00     6.5587246E+00     3.0087369E+01
        0.0932       1.0729177E+01     1.6000000E+03     6.7154590E-01     4.7468304E+00     1.0014500E+01     2.9825215E+01
```

9 Dynamic Aeroelastic Response Analysis

Overview

The dynamic aeroelastic response analysis provided in MSC Nastran is demonstrated in five applications: four applications use the BAH jet transport wing and one application uses the 15-deg sweptback wing.

Examples HA146A (p. 650), HA146B (p. 667), and HA146C (p. 679) are analyses of the transient response to a discrete gust, the random response to atmospheric turbulence, and the transient response to an aileron input for the BAH wing, respectively. For the discrete and random gust examples, the gust field is assumed to be uniform spanwise and the aircraft is free to plunge; the pitching and rolling degrees of freedom are constrained. For the aileron response example, motion is antisymmetric and the aircraft is free to roll while constrained in pitch and plunge. The aerodynamic loads on the wing-aileron combination are calculated using the Doublet-Lattice method at a Mach number of zero.

Examples HA146D and HA146DR (p. 698) are frequency response analyses of the BAH wing. A frequency response analysis is always done as a first step within the aeroelastic response solution. However, as demonstrated here, it may be done without any subsequent analysis (for example, random analysis) in the run.

Example HA146E (p. 713)provides an analysis of the response of the 15-deg sweptback wing to an impulsively applied load at the wing tip in order to investigate the transient response at subcritical, critical, and supercritical speeds. The structural and aerodynamic models are the same as in the subsonic flutter analysis described in Example HA145E (p. 469).

It should be noted that Case Control is an essential part of Dynamic Aeroelastic Analysis in that any output not requested in the Case Control Section or the Bulk Data Section will not be provided. In Static Aeroelastic Response and Aerodynamic Flutter analyses, certain output is provided by default. There is no default output from Dynamic Aeroelastic Response analysis.

Discrete Gust Response of BAH Wing (Example HA146A)

This example calculates the time history of the response of the BAH wing due to a gust load. The gust is a discrete, sharp-edged, symmetric, vertical gust.

The structural model in this example is the same as the model described in Example HA144B (p. 240). The structural input file is BAH_STRUCT.DAT and is shown in Listing 7-3; the inertial input file is BAH_MASS and is shown in Listing 7-4. The simplified aerodynamic box characteristics of Example HA145B (p. 428) are used here; the aerodynamic input file is BAH_AERO5.DAT and it is shown in Listing 8-4. The additional input data required by SOL 146 are described below.

The data set BAH_STRUCT.DAT provides all of the basic data for this example. It is necessary to alter constraints for the symmetrical condition considered here on SPC 14 to constrain the support (GRID 11) in roll and pitch. The wing is therefore only free in plunge to permit correlation with the gust response analysis of Bisplinghoff, Ashley, and Halfman (1955, pp. 682-685) [Reference 8].

It is also important to include structural damping in a gust response analysis. It is included here as modal structural damping via the tabular form in TABDMP1 2000 (along with SDAMP in Case Control). A realistic value of $g = 0.02$ is assumed to be constant in the frequency range from zero to 10.0 Hz. (Note that in the Fourier analyses in MSC Nastran tabular entries are not extrapolated beyond the tabulated range.)

The responses are calculated at a velocity of 475 mph (8360. in/s). This velocity is listed on the AERO entry along with the aerodynamic coordinate system that prescribes the positive x-coordinate downstream, the reference semichord, a sea-level density, and the symmetry flag selected for symmetrical motion. The aerodynamic model is INCLUDEd with the input file BAH_AERO5.DAT, which divides the wing into six strips (including one to represent the fuselage carry-over loads). The GUST 1000 entry defines the external aerodynamic load that comes from a stationary one-dimensional vertical gust. GUST 1000 defines the magnitude of the gust angle of attack with a scale factor $WG = 1.0$. It is desired to delay the application of the gust for 0.2 sec in order to observe if the response has damped out sufficiently during the previous period in the periodic Fourier solution. To obtain the 0.2 sec delay, the GUST entry defines the reference location of the gust at 1672 in. ($0.2\ \text{sec} \times 8360.\ \text{in/s}$) ahead of the aerodynamic coordinate system ($x_0 = -1672.0\ \text{in}$) and lists the airplane velocity (8360. in/s). The GUST entry also specifies the TLOAD1 1001 entry that defines the gust time history via the TABLED1 1003 entry. A square-edged gust of unit magnitude is defined in the table with a 1.0 second duration. Because the Fourier transform method is used in the MSC Nastran transient aeroelastic analysis, the accelerations, internal forces, stresses, and relative displacements characteristically will all approach some constant value (that is, show some relative response) and relative velocities will approach a value of zero at the end of each period. However, a technique can be used that results in each of these response quantities, except displacements, approaching a value of zero (that is, show an absolute response). The technique requires following the applied loading with an identical loading but in the opposite direction; the second loading could be delayed but that is not recommended). This technique is illustrated here. To represent the sharp-edged gust, the TABLED1 1003 entry defines a square-wave gust profile of sufficient duration to permit the peak response to occur, followed by the negative square-wave gust, and a sufficiently long period is used so that the response damps out adequately before the next period begins.

Another technique, not demonstrated here, would cause all of the response quantities, including displacements, to approach values of zero. This would follow the applied loading with the identical loading twice. The second loading would be in the opposite direction as the first but with twice the magnitude, and the third loading would have the same magnitude and direction as the first.

The response quantities determined when using either of these techniques are only valid during the application of the initial loading; they are not valid during or after the application of the second loading. For this reason, the initial loading must have sufficient duration so that all critical responses are achieved.

The DAREA 1002 entry called by the TLOAD1 1001 entry has no influence on the load; it is a dummy entry required by the presence of the TLOAD1 entry. However, the entry must specify at least one point, component, and area. Only the DAREA entry associated with the GUST entry is a dummy; if other loads are prescribed in the analysis, DAREA entries associated with these other applied loads would be used.

The MKAERO1 entry selects the Mach numbers and reduced frequencies used in generating the aerodynamic matrices. The Mach number is 0.62. The reduced frequencies, $k = \omega\bar{c}/2V$, are based on the velocity and reference chord from the AERO entry. At the cut-off frequency of 10.0 Hz, selected here to include the first four modes, and the 475 mph velocity, the reduced frequency is 0.493. Values of $k = 0.001$, 0.02, 0.10, and 0.50 are specified on the MKAERO1 entry to represent the range of reduced frequencies.

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The PARAM,GUSTAERO entry is set to -1 in order for the harmonic gust aerodynamic coefficients to be calculated in addition to the aerodynamic coefficients for harmonic motion. When there are prescribed applied loads but no gust loading in the transient response analysis, neither the PARAM,GUSTAERO nor the GUST entries are required. The flight condition is additionally specified by the Mach number on the PARAM,MACH,0.62 entry and dynamic pressure on the PARAM,Q,4.00747 entry.

The ElGR entry selects the eigenvalue method for the vibration modes to be calculated and subsequently used for the modal formulation. The rigid body plunge mode and all 10 elastic modes are calculated. They are determined using the Modified Givens (MGIV) method and are normalized to their maximum displacements with MAX.

The determination of the root bending moment at the side of the fuselage, GRID 11, is the primary objective of this gust analysis. The stress data recovery method used to determine the bending moment is the default Matrix method. (The stress data recovery method is selected by PARAM,DDRMM; the default value is 0 and is more economical when the number of output time steps is large. The Mode Displacement method is selected by PARAM,DDRMM,-1.) To increase the accuracy of the results from the Matrix method, all 11 wing modes are included in the modal formulation.

The range of frequencies for which the solution is performed is selected by the FREQ1 40 entry. The frequency range includes the first elastic mode, which is wing bending at $f = 2.44\text{ Hz}$. As more modes are included within the frequency range, the accuracy of the solution increases. Therefore a 10.0 Hz frequency range is chosen that includes the next two elastic modes at 3.56 and 8.53 Hz. 80 frequencies with a $\Delta f = \text{DF} = 0.125\text{ Hz}$ interval are selected. Because equally spaced frequencies are selected, the FREQ1 entry is appropriate to input the data. The period of the solution for equally spaced frequencies is $T = 1/\Delta f = 8.0\text{ sec}$, that is, the solution will repeat every 8.0 seconds.

The Fourier transformation parameters for SOL 146 must be selected to represent both the resonance characteristics of the structure, the duration of the loading, and the requirement to return to the initial conditions at the end of the period. Closely spaced frequencies are necessary near the resonance frequencies, and small frequency intervals are necessary to obtain a period that is large relative to the duration of the applied loading. For these reasons, the FREQ1 entry is recommended with small, equal frequency intervals.

The TSTEP 41 entry defines the output time steps by their number and increment and includes a skip factor for output. The output time steps have no influence on the solution as they do in a transient response analysis by numerical integration; they are only used to specify the output time steps. The period is 8.0 seconds, so 320 time steps of 0.025 seconds increments are specified for printing and plotting. ENDDATA is the last entry in the Bulk Data Section.

Case Control Command

The Case Control Section contains the TITLE, SUBTITLE, and LABEL entries. ECHO = BOTH echoes all of the Bulk Data with and without annotations. SPC = 14 selects the constraints. METHOD = 10 selects the ElGR entry for the vibration analysis. SDAMP = 2000 selects the uniform two percent modal structural damping. FREQ = 40 selects the frequency list and TSTEP = 41 selects the time history output. GUST = 1000 selects the gust load. The DLOAD entry is required in SOL 146 in the Case Control Section even when there are only gust loads. SDlSP(PLOT) = 1 and DISP(PLOT) = 2 specify the SET 1 and SET 2 points for determining modal and physical displacements to be plotted. SPCF = 3 causes the constraint forces, that is,

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the root bending moment at GRID 11, to be printed. Following OUTPUT(XYOUT) are the XYPLOT requests. Before the first XYPLOT request are several optional statements that define the plot frame and the plot titles. XYPLOTS are requested for the first and second modes and the bending moment at the root. The BEGIN BULK command completes the Case Control Section.

The Executive Control Section begins with the identification ID MSC, HA146A that denotes Problem No. HA146A in the Test Problem Library. TIME 10 limits CPU time to 10.0 minutes. SOL 146 calls for the Dynamic Aeroelastic Response Solution. The CEND statement completes the Executive Control Section.

Output

The input data are shown in Listing 9-1 and sorted Bulk Data entries are in Listing 9-2. Listing 9-3 presents typical output and is discussed briefly below.

Under the heading REAL EIGENVALUES are the natural frequencies of the structural model. The first is the rigid body (z-translation) mode followed by 10 elastic modes.

Of the 11 modal responses calculated for the aeroelastic response solution, the first and second responses are printed and are plotted in Figure 9-1 and Figure 9-2. The wing aft tip deflection at GRID 10 is also printed and is plotted in Figure 9-3; the limited effect of the wing dynamics is seen as the deflection follows the rigid body mode (see Figure 9-1 and Figure 9-3).

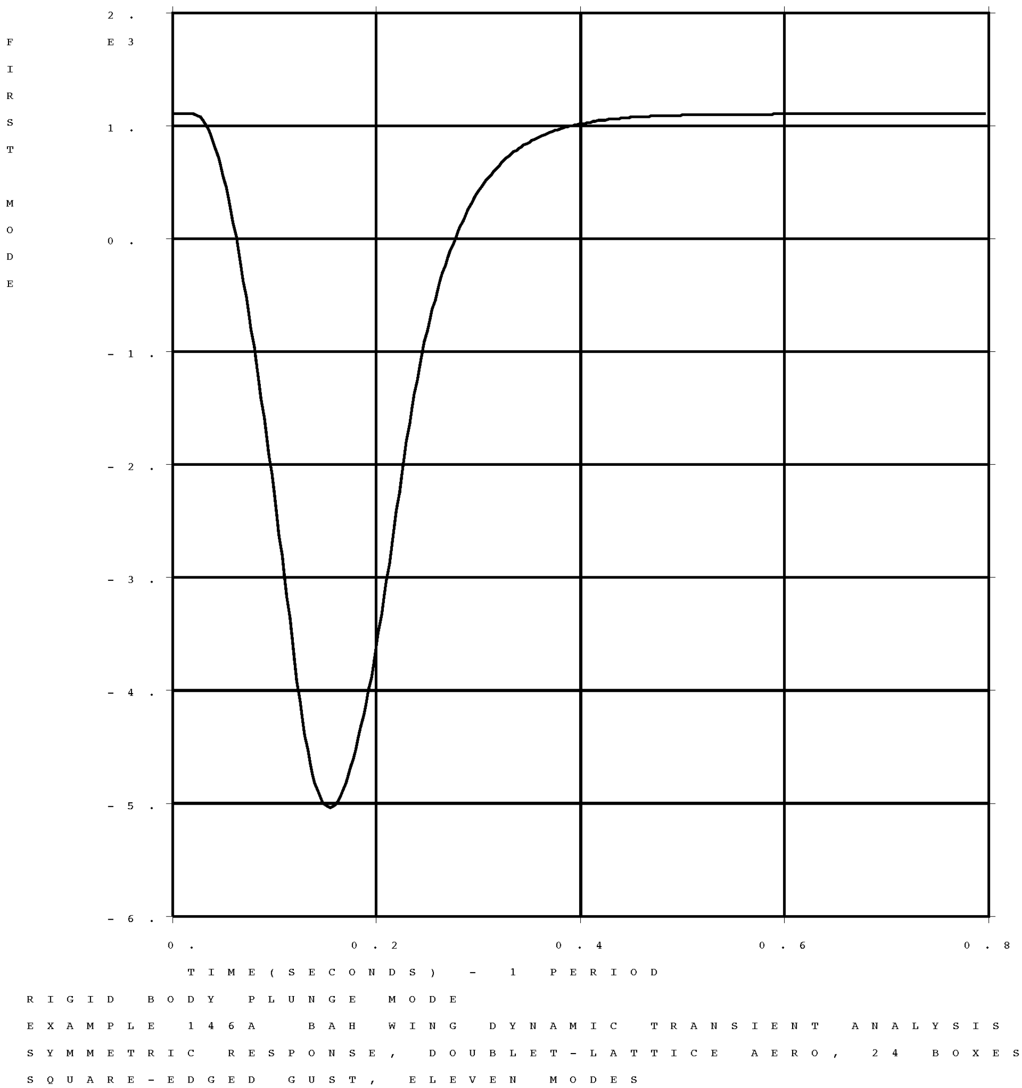


Figure 9-1 Response of Rigid Body Plunge Mode

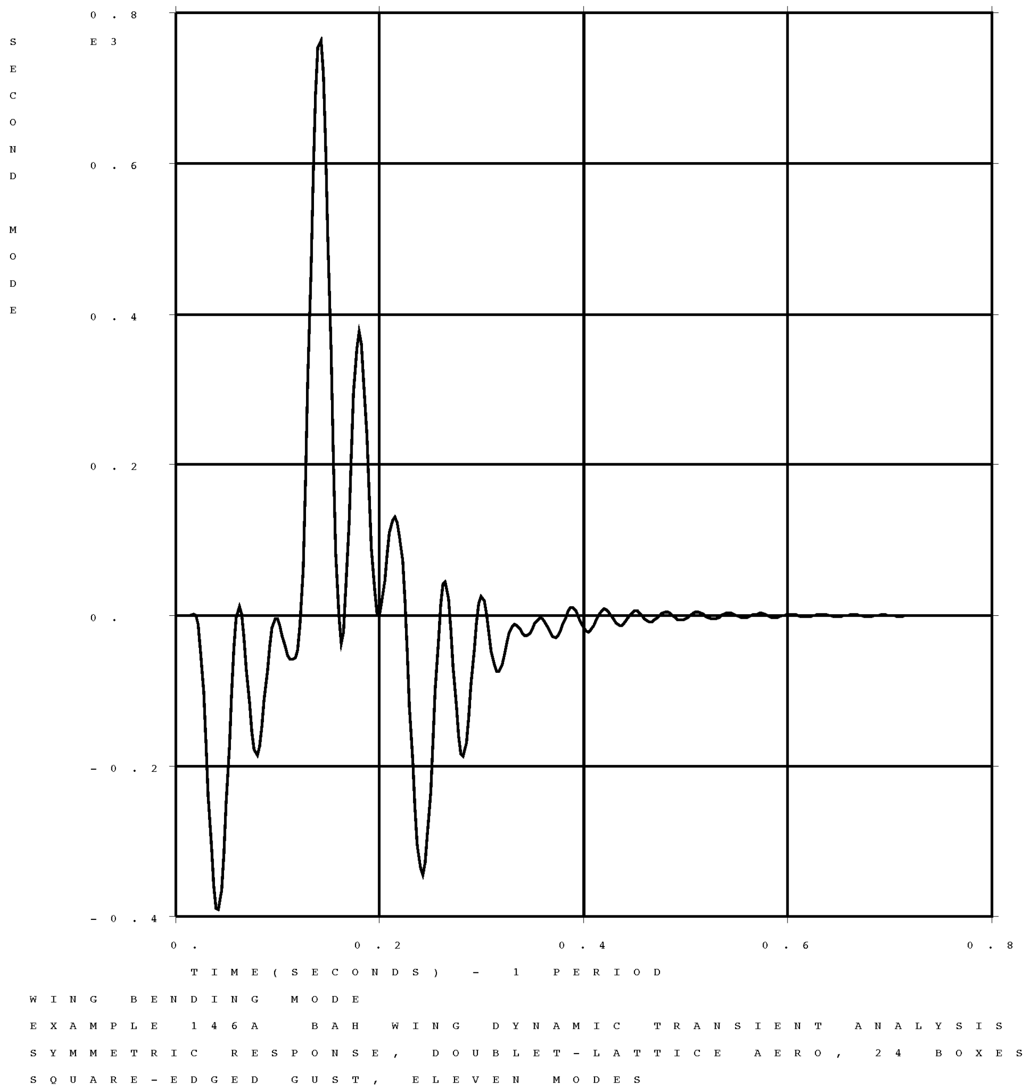


Figure 9-2 Response of First Wing Bending Mode

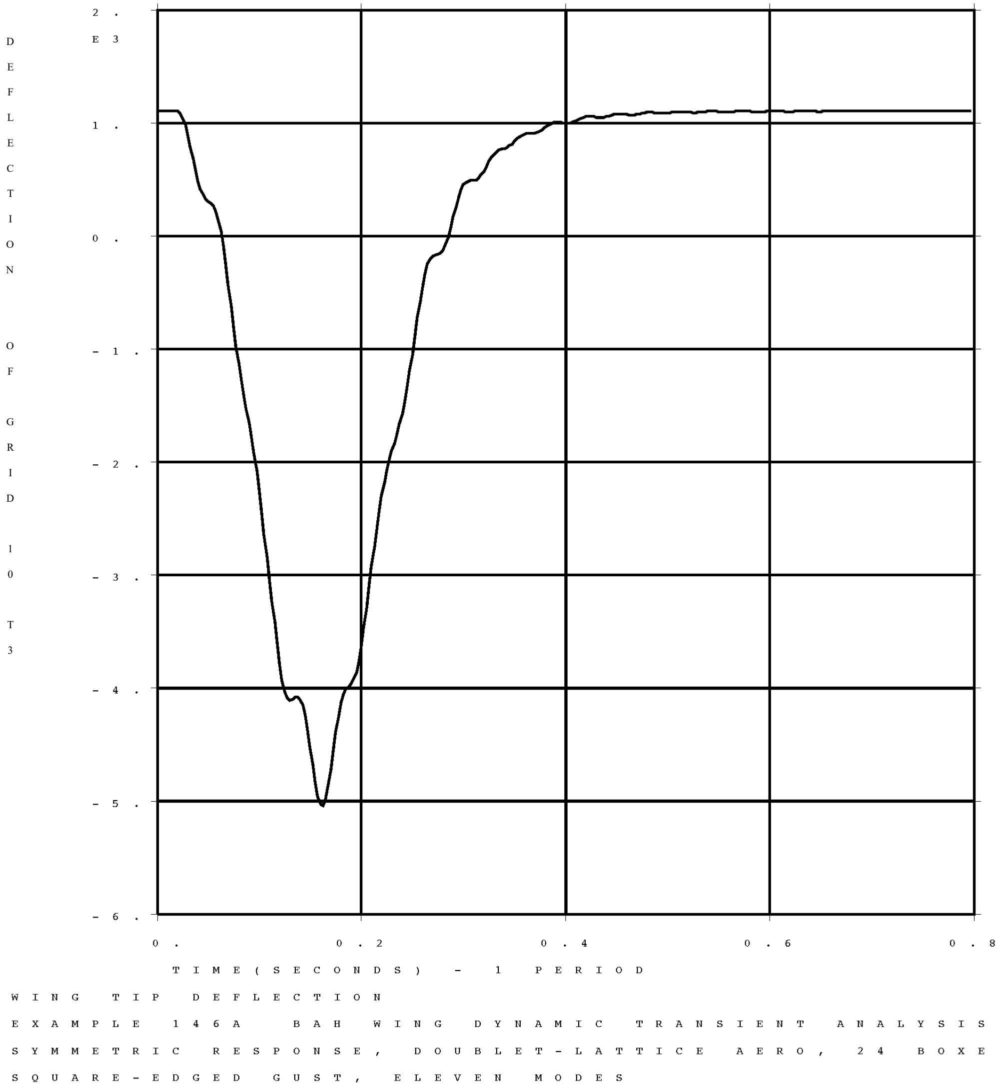


Figure 9-3 Response of Wing Aft Tip Deflection

The root bending moment is printed under the heading of FORCES OF SINGLE-POINT CONSTRAINT for GRID 11 column R3 and is plotted in Figure 9-4.

Because certain approximations are made regarding the Fourier series, and due to the method in which the gust load was applied, the printed and plotted output show the absolute response of the SPC forces but only the relative response of the displacements. This is evident for the rigid body plunge mode (Figure 9-1) since this response begins and ends with some nonzero value.

Inspection of the plots shows the 0.2 second delay and that the response is damped out by the end of the period. The amplitude of the wing first bending mode in Figure 9-2 goes to zero (the relative displacement returns to its initial constant value) after a few seconds and the wing returns to its trimmed condition.

Example 10-5 from Bisplinghoff, Ashley, and Halfman (1955, pp. 682-685) [Reference 8] shows the dynamic bending moment calculated at the wing root of the BAH wing at 475 mph due to a sharp-edged gust, including the plunging of the airplane and the first bending mode of the wing, and calculating the aerodynamic loads by quasi-steady aerodynamic strip theory. The comparison can therefore only be qualitative because of the many more vibration modes and unsteady aerodynamic lifting surface theory used here.

The GENEL entry is used to input the flexibility of the structure and defines nonstandard rotational degrees of freedom for GRID 11. R1 and R2 are rolling and pitching degrees of freedom respectively, and R3 represents the wing root bending degree of freedom. The GENEL for the BAH wing has been discussed in Example HA144B (p. 240). The column in the output FORCES OF SINGLE-POINT CONSTRAINT labeled R3 provides the desired data for wing root bending moment. The peak response of the wing occurs at about 25 semichords into the gust. The inset in Figure 9-4 is Figure 10-24 of Bisplinghoff, Ashley, and Halfman (1955) [Reference 8], and the qualitative comparison is good. The MSC Nastran peak response is 2.76×10^8 in-lb $(1.9 \times 10^7$ ft-lb$)$ in the travel distance of 27 semichords as compared to 2.04×10^8 in-lb $(1.7 \times 10^7$ ft-lb$)$ in 23 semichords in Bisplinghoff, Ashley, and Halfman (1955) [Reference 8].

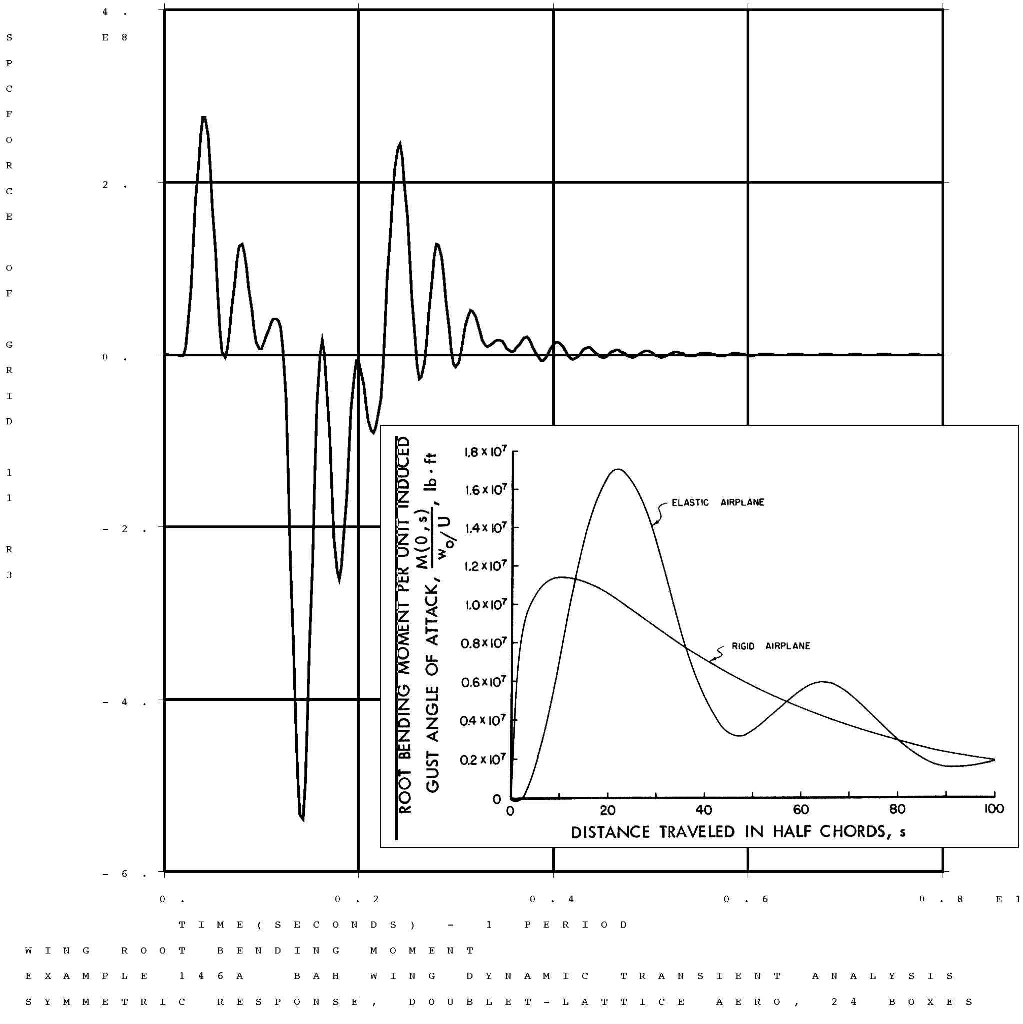


Figure 9-4 Wing Root Bending Moment [Inset compares results from Bisplinghoff, Ashley and Halfman (1955, Figure 10-24)]

Listing 9-1 Input Files for Discrete Gust Response of BAH Wing

```
 N A S T R A N    E X E C U T I V E    C O N T R O L    D E C K    E C H O


ID MSC, HA146A
$$$$$$$$        HANDBOOK FOR AEROELASTIC ANALYSIS EXAMPLE HA146A                $$$$$$$$
$                                                                                      $
$       MODEL DESCRIPTION       BAH JET TRANSPORT WING FREE IN PLUNGE.                 $
$                               SYMMETRIC RESPONSE TO A SQUARE EDGE GUST        .      $
$                                                                                      $
$       SOLUTION                TRANSIENT ANALYSIS USING DOUBLET-LATTICE               $
$                               METHOD AERODYNAMICS AT MACH NO. OF 0.62.               $
$                               AT MACH NO. OF 0.62                                    $
$                                                                                      $
$       OUTPUT                  XY PLOTS OF MODAL AND GRID POINT                       $
$                               DISPLACEMENTS AND WING ROOT BENDING                    $
$                               MOMENT TIME HISTORIES.                                 $
$                                                                                      $
$$$$$$$$                                                                        $$$$$$$$
TIME 10   $ CPU TIME IN MINUTES
SOL  146  $ AEROELASTIC DYNAMIC RESPONSE
CEND



EXAMPLE HA146A: BAH WING DYNAMIC TRANSIENT ANALYSIS                                                                  PAGE      2
 SYMMETRIC RESPONSE, DOUBLET-LATTICE AERO, 24 BOXES

 SQUARE-EDGE GUST, ELEVEN MODES
                                           C A S E    C O N T R O L    D E C K    E C H O
           CARD
           COUNT
            1      TITLE = EXAMPLE HA146A: BAH WING DYNAMIC TRANSIENT ANALYSIS
            2      SUBTITLE = SYMMETRIC RESPONSE, DOUBLET-LATTICE AERO, 24 BOXES
            3      LABEL = SQUARE-EDGED GUST, ELEVEN MODES
            4        ECHO = BOTH
            5        SPC = 14                $ BOUNDARY CONDITIONS (SYMMETRIC, NO PITCH)
            6        METHOD = 10             $ MODIFIED GIVENS EIGENVALUE METHOD
            7        SDAMP = 2000            $ STRUCTURAL DAMPING (2 PERCENT)
            8        GUST  = 1000            $ AERODYNAMIC LOADING (SQUARE GUST)
            9        DLOAD = 1001            $ REQUIRED
           10        FREQ = 40               $ FREQUENCY LIST
           11        TSTEP = 41              $ SOLUTION TIME STEPS (1 PERIOD)
           12      OUTPUT
           13        SET 1 = 1, 2
           14        SET 2 = 10
           15        SET 3 = 11
           16        SDISP(PRINT,PLOT) = 1         $ MODAL DISPLACEMENTS
           17        DISP(PRINT,PLOT) = 2          $ STRUCTURAL GRID POINT DISPLACEMENTS
           18        SPCF = 3                $ CONSTRAINT FORCES
           19      OUTPUT(XYOUT)             $ XY PLOTTING PACKAGE
           20        CSCALE 2.0
           21        PLOTTER = NASTRAN
           22        XMIN   = 0.
           23        XMAX   = 8.0
           24        UPPER TICS = -1
           25        RIGHT TICS = -1
           26        XGRID LINES = YES
           27        YGRID LINES = YES
           28        TCURVE = RIGID BODY PLUNGE MODE
           29        XTITLE = TIME(SECONDS) - 1 PERIOD
           30        YTITLE = FIRST MODE
           31       XYPLOT    SDISP /    1(T1)
           32        TCURVE = WING BENDING MODE
           33        YTITLE = SECOND MODE
           34       XYPLOT    SDISP /    2(T1)
           35        TCURVE = WING TIP DEFLECTION
           36        YTITLE = DEFLECTION OF GRID 10 T3
           37       XYPLOT    DISP/ 10(T3)
           38        TCURVE = WING ROOT BENDING MOMENT
           39        YTITLE = SPCFORCE OF GRID 11 R3
           40       XYPLOT    SPCF /  11(R3)
           41      BEGIN BULK
```

Listing 9-1 Input Files for Discrete Gust Response of BAH Wing (Continued)

```
EXAMPLE HA146A: BAH WING DYNAMIC TRANSIENT ANALYSIS                                                     PAGE     3
 SYMMETRIC RESPONSE, DOUBLET-LATTICE AERO, 24 BOXES

 SQUARE-EDGE GUST, ELEVEN MODES
                                        I N P U T   B U L K   D A T A   D E C K   E C H O

                         .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                         $
                         $* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                         INCLUDE BAH_STRUCT.DAT
                         $
                         INCLUDE BAH_MASS.DAT
                         $
                         $        TABDMP1 DEFINES DAMPING COEFFICIENTS (G1) VERSES FREQUENCY (F1).
                         $        (2.0 PERCENT STRUCTURAL DAMPING IS SPECIFIED OVER THE ENTIRE
                         $        FREQUENCY RANGE.  VALUES ARE LINEARLY INTERPOLATED AND
                         $        EXTRAPOLATED.  A 2.0 PERCENT STRUCTURAL DAMPING IS ROUGHLY
                         $        EQUIVALENT TO 1.0 PERCENT CRITICAL DAMPING.)
                         $
                         $       ID      TYPE
                         TABDMP1 2000                                                    +TABDMP
                         $       F1      G1      F2      G2     "ENDT"
                         +TABDMP 0.      .02     10.     .02     ENDT
                         $
                         $                        * * CONSTRAINTS * *
                         $
                         $        THE SPC ENTRY CONSTRAINS DOFS.
                         $
                         $       SID     G       C       D
                         SPC     14      11      45
                         $
                         $* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                         $
                         $                      * * * AERODYNAMIC DATA * * *
                         $
                         $                (THIS MODEL USES THE LB-IN-SEC SYSTEM)
                         $
                         $        THE AERO ENTRY DEFINES BASIC AERODYNAMIC PARAMETERS. ACSID IS THE
                         $        AERO COORDINATE SYSTEM. VELOCITY. REFC IS THE REFERENCE
                         $        COORDINATE SYSTEM. RHOREF IS REFERENCE DENSITY. SYMXZ AND
                         $        SYMXY ARE SYMMETRY KEYS.
                         $
                         $       ACSID   VELOCITY REFC   RHOREF  SYMXZ   SYMXY
                         AERO    1       8360.   131.25  1.1468-71
                         $
                         INCLUDE BAH_AERO5.DAT
                         $
                         $* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                         $
                         $                  * * DYNAMIC LOAD AND RESPONSE DATA * *
                         $
                         $        GUST DEFINES A STATIONARY VERTICAL GUST.  LISTED ARE T/RLOAD ENTRY
                         $        ID, GUST ANGLE OF ATTACK (that is, THE RATIO OF GUST VELOCITY TO THE
                         $        VEHICLE VELOCITY), LOCATION OF THE GUST WITH RESPECT TO THE ORIGIN
                         $        OF THE AERO COORDINATE SYSTEM, AND THE VEHICLE VELOCITY.
                         $
                         $       SID     DLOAD   WG      X0      V
                         GUST    1000    1001    1.0     -1672.  8360.
                         $
                         $        TLOAD1 DEFINES A TIME DEPENDENT DYNAMIC LOAD OR ENFORCED MOTION.
                         $        LISTED ARE THE ID, DAREA ID, DELAY ID, TYPE OF DYNAMIC EXCITATION,
                         $        AND TABELDI ID.
                         $
                         $       SID     DAREA   DELAY   TYPE    TID
                         TLOAD1  1001    1002                    1003
                         $
                         $        DAREA DEFINES THE DOF WHERE THE LOAD IS APPLIED AND A SCALE FACTOR.
                         $
                         $       SID     P       C       A
                         DAREA   1002    11      1       0.
                         $
                         $        TABLED1 DEFINES A TABULAR FUNCTION OF A TIME-DEPENDENT LOAD.
                         $
                         $       SID
                         TABLED1 1003                                                    +TAB1
                         $       X1      Y1      X2      Y2      X3      Y3      X4      Y4
                         +TAB1   0.      1.      1.      1.      1.      -1.     2.      -1.     +TAB2
                         $       X5      Y5
                         +TAB2   ENDT
                         $
```

Listing 9-1 Input Files for Discrete Gust Response of BAH Wing (Continued)

```
$        THE MKAERO1 ENTRY DEFINES COMBINATIONS OF MACH NUMBER AND REDUCED
$        FREQUENCY EACH OF WHICH WILL BE USED TO GENERATE A MATRIX OF
$        GENERALIZED AERODYNAMIC FORCES.
$
$       M1      M2      M3      M4
MKAERO1 .62                                                             +MK
$        K1      K2      K3      K4
+MK     .001    .02     0.10    0.50
$
$       PARAM,GUSTAERO,-1 IS REQUIRED IF GUST LOADS ARE TO BE COMPUTED.
$
PARAM   GUSTAERO -1
$
$       PARAM,MACH SPECIFIES DYNAMIC PRESSURE.
$
PARAM   MACH    0.62
$
$       PARAM,Q SPECIFIES DYNAMIC PRESSURE.
$
PARAM   Q       4.00747
$
$        EIGR DEFINES EIGENVALUE EXTRACTION DATA.  LISTED ARE THE
$        EIGENVALUE EXTRACTION METHOD, FREQUENCY RANGE, NUMBER OF
$        EXPECTED AND DESIRED ROOTS AND THE METHOD OF NORMALIZATION.
$
$       SID     METHOD  F1      F2      NE      ND
EIGR    10      MGIV                            11                      +EIGR
$       NORM
+EIGR   MAX
$
$        PARAM,LMODES,N SPECIFIES THAT N MODES ARE TO BE USED IN
$        THE ANALYSIS.
$
PARAM   LMODES  11
$
$        FREQ1 DEFINES THE SET OF FREQUENCIES USED TO OBTAIN
$        THE FREQUENCY RESPONSE SOLUTION. LISTED ARE THE STARTING
$        FREQUENCY, FREQUENCY INCREMENT AND NUMBER OF INCREMENTS.
$
$       SID     F1      DF      NDF
FREQ1   40      0.      .125    80
$
$        TSTEP DEFINES TIME STEP INTERVALS AT WHICH THE TRANSIENT
$        RESPONSES ARE DESIRED.  LISTED ARE  THE NUMBER OF STEPS,
$        THE TIME INTERVAL AND SKIP FACTOR FOR OUTPUT.
$
$       SID     N       DT      NO
TSTEP   41      320     .025    1
$
ENDDATA

INPUT BULK DATA CARD COUNT =     334
```

Listing 9-2 Sorted Bulk Data for Discrete Gust Response of BAH Wing

```
EXAMPLE HA146A: BAH WING DYNAMIC TRANSIENT ANALYSIS                                                      PAGE    10
 SYMMETRIC RESPONSE, DOUBLET-LATTICE AERO, 24 BOXES

 SQUARE-EDGE GUST, ELEVEN MODES
                                             S O R T E D   B U L K   D A T A   E C H O
           CARD
           COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
             1-         AEFACT  77      .0      .09     .276    .454    .636    .826    1.0
             2-         AERO    1       8360.   131.25  1.1468-71
             3-         CAERO1  1001    1000    0               4       77              1       +CA1
             4-         +CA1    78.75   0.0     0.0     225.0   35.0    500.0   0.0     100.0
             5-         CMASS2  121     5248.7  1       3
             6-         CMASS2  122     134.9   1       3       2       3
             7-         CMASS2  123     790.3   2       3
             8-         CMASS2  341     9727.   3       3
             9-         CMASS2  342     11005.  3       3       4       3
            10-         CMASS2  343     473.    4       3
            11-         CMASS2  561     3253.6  5       3
            12-         CMASS2  562     -139.7  5       3       6       3
            13-         CMASS2  563     946.3   6       3
            14-         CMASS2  781     2617.8  7       3
            15-         CMASS2  782     21.     7       3       8       3
            16-         CMASS2  783     782.3   8       3
            17-         CMASS2  9101    494.8   9       3
            18-         CMASS2  9102    -7.3    9       3       10      3
            19-         CMASS2  9103    185.2   10      3
            20-         CONM1   1       11                                                      +51
            21-         +51     17400.                          4.37+7                          +52
            22-         +52             4.35+09
            23-         CORD2R  1               0.      0.      0.      0.      0.      -1.     +C1
            24-         +C1     -1.     0.      0.
            25-         DAREA   1002    11      1       0.
            26-         EIGR    10      MGIV                            11                      +EIGR
            27-         +EIGR   MAX
            28-         FREQ1   40      0.      .125    80
            29-         GENEL   432             1       3       2       3       3       3       +01
            30-         +01     4       3       5       3       6       3       7       3       +02
            31-         +02     8       3       9       3       10      3                       +03
            32-         +03     UD              11      3       11      4       11      5       +04
            33-         +04     11      6                                                       +05
            34-         +05     Z       8.7172-61.3361-61.2778-56.2720-61.6251-51.0492-52.0478-5+06
            35-         +06     1.5630-52.4285-52.0403-53.0861-56.2720-63.2297-51.0492-53.3529-5+07
            36-         +07     1.5630-53.5021-52.0257-53.5785-52.7732-51.5726-54.8255-53.7628-5+08
            37-         +08     7.3284-56.4338-59.5810-58.8378-56.3749-53.7628-58.0136-56.4338-5+09
            38-         +09     1.0012-48.8378-51.1811-41.2758-41.1344-41.9350-41.8160-42.5283-4+10
            39-         +10     2.4294-41.6999-41.8160-42.2920-42.4294-42.8249-43.6862-43.5052-4+11
            40-         +11     5.2675-45.1171-44.2292-45.1171-45.7187-48.4840-48.2340-49.2340-4+12
            41-         +12     S       1.0     90.0    -20.25  45.0    1.0     90.0    81.0    +13
            42-         +13     45.0    1.0     186.0   -17.85  141.0   1.0     186.0   71.4    +14
            43-         +14     141.0   1.0     268.0   -15.80  223.0   1.0     268.0   63.2    +15
            44-         +15     223.0   1.0     368.0   -13.30  323.0   1.0     368.0   53.2    +16
            45-         +16     323.0   1.0     458.0   -11.05  413.0   1.0     458.0   44.2    +17
            46-         +17     413.0
            47-         GRID    1               20.25   90.                     12456
            48-         GRID    2               -81.    90.                     12456
            49-         GRID    3               17.85   186.                    12456
            50-         GRID    4               -71.4   186.                    12456
            51-         GRID    5               15.8    268.                    12456
            52-         GRID    6               -63.2   268.                    12456
            53-         GRID    7               13.3    368.                    12456
            54-         GRID    8               -53.2   368.                    12456
            55-         GRID    9               11.05   458.                    12456
            56-         GRID    10              -44.2   458.                    12456
            57-         GRID    11              0.0     0.                      126
            58-         GUST    1000    1001    1.0     -1672.  8360.
            59-         MKAERO1 .62                                                             +MK
            60-         +MK     .001    .02     0.10    0.50
            61-         PAERO1  1000
            62-         PARAM   GRDPNT  11
            63-         PARAM   GUSTAERO-1
            64-         PARAM   LMODES  11
            65-         PARAM   MACH    0.62
            66-         PARAM   Q       4.00747
            67-         PARAM   WTMASS  .0025907
            68-         SET1    14      1       THRU    11
            69-         SPC     14      11      45
            70-         SPLINE2 100     1001    1005    1024    14      0.0     1.0     0       +SP100
            71-         +SP100  -1.0    -1.0
            72-         TABDMP1 2000                                                            +TABDMP
            73-         +TABDMP 0.      .02     10.     .02     ENDT
            74-         TABLED1 1003                                                            +TAB1
            75-         +TAB1   0.      1.      1.      1.      1.      -1.     2.      -1.     +TAB2
            76-         +TAB2   ENDT
            77-         TLOAD1  1001    1002                    1003
            78-         TSTEP   41      48      .025    1
                        ENDDATA
        TOTAL COUNT=        79
```

Listing 9-3 Output for Discrete Gust Response of BAH Wing

```
EXAMPLE HA146A: BAH WING DYNAMIC TRANSIENT ANALYSIS                                                     PAGE    13
 SYMMETRIC RESPONSE, DOUBLET-LATTICE AERO, 24 BOXES

 SQUARE-EDGE GUST, ELEVEN MODES
                       O U T P U T   F R O M   G R I D   P O I N T   W E I G H T   G E N E R A T O R

                                               REFERENCE POINT =       11
                                                          M O
                  *  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00 *
                  *  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00 *
                  *  0.000000E+00  0.000000E+00  4.191900E+04  5.128960E+06 -1.642074E+05  0.000000E+00 *
                  *  0.000000E+00  0.000000E+00  5.128960E+06  1.350243E+09 -2.381847E+07  0.000000E+00 *
                  *  0.000000E+00  0.000000E+00 -1.642074E+05 -2.381847E+07  4.458782E+09  0.000000E+00 *
                  *  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00 *
                                                           S
                                     *  1.000000E+00  0.000000E+00  0.000000E+00 *
                                     *  0.000000E+00  1.000000E+00  0.000000E+00 *
                                     *  0.000000E+00  0.000000E+00  1.000000E+00 *
                         DIRECTION
                    MASS AXIS SYSTEM (S)     MASS              X-C.G.        Y-C.G.        Z-C.G.
                                X           0.000000E+00      0.000000E+00  0.000000E+00  0.000000E+00
                                Y           0.000000E+00      0.000000E+00  0.000000E+00  0.000000E+00
                                Z           4.191900E+04      3.917256E+00  1.223541E+02  0.000000E+00
                                                          I(S)
                                     *  7.226942E+08  3.727022E+06  0.000000E+00 *
                                     *  3.727022E+06  4.458139E+09  0.000000E+00 *
                                     *  0.000000E+00  0.000000E+00  0.000000E+00 *
                                                          I(Q)
                                     *  4.458143E+09                             *
                                     *                7.226906E+08               *
                                     *                              0.000000E+00 *
                                                           Q
                                     *  9.977437E-04  9.999995E-01  0.000000E+00 *
                                     * -9.999995E-01  9.977437E-04  0.000000E+00 *
                                     *  0.000000E+00  0.000000E+00  1.000000E+00 *

                                           R E A L   E I G E N V A L U E S
MODE    EXTRACTION      EIGENVALUE            RADIANS             CYCLES            GENERALIZED         GENERALIZED
 NO.       ORDER                                                                       MASS              STIFFNESS
    1         1        1.705303E-13        4.129531E-07        6.572353E-08        1.085996E+02        1.851951E-11
    2         2        2.344038E+02        1.531025E+01        2.436702E+00        7.333811E+00        1.719073E+03
    3         3        5.021460E+02        2.240862E+01        3.566442E+00        4.860579E+01        2.440721E+04
    4         4        2.873470E+03        5.360476E+01        8.531462E+00        6.036275E+00        1.734505E+04
    5         5        6.346819E+03        7.966693E+01        1.267939E+01        1.389629E+01        8.819726E+04
    6         6        8.746056E+03        9.352035E+01        1.488422E+01        3.997501E+00        3.496237E+04
    7         9        1.766041E+04        1.328925E+02        2.115050E+01        3.884947E+00        6.860977E+04
    8         8        2.401137E+04        1.549560E+02        2.466202E+01        3.570773E+00        8.573913E+04
    9        11        4.211877E+04        2.052286E+02        3.266314E+01        3.142323E+00        1.323508E+05
   10        10        6.020940E+04        2.453760E+02        3.905281E+01        1.016273E+00        6.118916E+04
   11         7        9.492829E+04        3.081043E+02        4.903633E+01        8.935863E+00        8.482661E+05
```

Listing 9-3 Output for Discrete Gust Response of BAH Wing (Continued)

```
    POINT-ID =         1
                                          D I S P L A C E M E N T   V E C T O R   (SOLUTION SET)

     TIME       TYPE          T1             T2             T3             R1             R2             R3
 0.0              M      1.109709E+03
 2.500000E-02     M      1.109659E+03
 5.000000E-02     M      1.109616E+03
 7.500000E-02     M      1.109698E+03
 1.000000E-01     M      1.109774E+03
 1.250000E-01     M      1.109665E+03
 1.500000E-01     M      1.109628E+03
 1.750000E-01     M      1.109992E+03
 2.000000E-01     M      1.109896E+03
 2.250000E-01     M      1.106718E+03
 2.500000E-01     M      1.097344E+03
 2.750000E-01     M      1.079960E+03
 3.000000E-01     M      1.054306E+03
 3.250000E-01     M      1.020472E+03
 3.500001E-01     M      9.781787E+02
 3.750001E-01     M      9.272354E+02
 4.000001E-01     M      8.680320E+02
 4.250001E-01     M      8.011689E+02
 4.500001E-01     M      7.269859E+02
 4.750001E-01     M      6.457274E+02
 5.000001E-01     M      5.578156E+02
 5.250000E-01     M      4.635912E+02
 5.500000E-01     M      3.630183E+02
 5.750000E-01     M      2.559458E+02
 6.000000E-01     M      1.424827E+02
 6.249999E-01     M      2.289102E+01
 6.499999E-01     M     -1.026384E+02
 6.749999E-01     M     -2.337794E+02
 6.999999E-01     M     -3.698208E+02
 7.249998E-01     M     -5.099340E+02
 7.499998E-01     M     -6.535629E+02
 7.749998E-01     M     -8.003328E+02
 7.999998E-01     M     -9.498253E+02
 8.249997E-01     M     -1.101808E+03
 8.499997E-01     M     -1.256537E+03
 8.749997E-01     M     -1.414464E+03
 8.999997E-01     M     -1.575782E+03
 9.249997E-01     M     -1.740556E+03
 9.499996E-01     M     -1.909026E+03
 9.749996E-01     M     -2.081293E+03
 9.999996E-01     M     -2.256867E+03
 1.025000E+00     M     -2.435018E+03
 1.050000E+00     M     -2.615432E+03
 1.075000E+00     M     -2.797921E+03
 1.100000E+00     M     -2.981789E+03
 1.125000E+00     M     -3.166401E+03
 1.149999E+00     M     -3.352308E+03
 1.174999E+00     M     -3.540389E+03
 1.199999E+00     M     -3.729090E+03
```

Listing 9-3 Output for Discrete Gust Response of BAH Wing (Continued)

```
    POINT-ID =        2
                                              D I S P L A C E M E N T   V E C T O R   (SOLUTION SET)

       TIME       TYPE          T1              T2              T3              R1              R2              R3
 0.0               M     -1.064374E-01
 2.500000E-02      M     -3.560842E-01
 5.000000E-02      M     -4.877727E-01
 7.500000E-02      M     -4.154845E-02
 1.000000E-01      M      3.323708E-01
 1.250000E-01      M     -9.691008E-02
 1.500000E-01      M     -2.032860E-01
 1.750000E-01      M      1.275305E+00
 2.000000E-01      M      6.706439E-01
 2.250000E-01      M     -1.178898E+01
 2.500000E-01      M     -4.526402E+01
 2.750000E-01      M     -1.003895E+02
 3.000000E-01      M     -1.690780E+02
 3.250000E-01      M     -2.407879E+02
 3.500001E-01      M     -3.066593E+02
 3.750001E-01      M     -3.585891E+02
 4.000001E-01      M     -3.884948E+02
 4.250001E-01      M     -3.909465E+02
 4.500001E-01      M     -3.655805E+02
 4.750001E-01      M     -3.162392E+02
 5.000001E-01      M     -2.493268E+02
 5.250000E-01      M     -1.738578E+02
 5.500000E-01      M     -1.010919E+02
 5.750000E-01      M     -4.173491E+01
 6.000000E-01      M     -3.091099E+00
 6.249999E-01      M      1.131507E+01
 6.499999E-01      M      1.337561E+00
 6.749999E-01      M     -2.899006E+01
 6.999999E-01      M     -7.137068E+01
 7.249998E-01      M     -1.158455E+02
 7.499998E-01      M     -1.537732E+02
 7.749998E-01      M     -1.785100E+02
 7.999998E-01      M     -1.854547E+02
 8.249997E-01      M     -1.736768E+02
 8.499997E-01      M     -1.469902E+02
 8.749997E-01      M     -1.118702E+02
 8.999997E-01      M     -7.460221E+01
 9.249997E-01      M     -4.099039E+01
 9.499996E-01      M     -1.669904E+01
 9.749996E-01      M     -5.077317E+00
 9.999996E-01      M     -5.044904E+00
 1.025000E+00      M     -1.303017E+01
 1.050000E+00      M     -2.611736E+01
 1.075000E+00      M     -4.123087E+01
 1.100000E+00      M     -5.318550E+01
 1.125000E+00      M     -5.796115E+01
 1.149999E+00      M     -5.749806E+01
 1.174999E+00      M     -5.560089E+01
 1.199999E+00      M     -4.667730E+01
```

Listing 9-3 Output for Discrete Gust Response of BAH Wing (Continued)

```
 POINT-ID =      10
                                             D I S P L A C E M E N T   V E C T O R

    TIME       TYPE          T1             T2             T3             R1             R2             R3
0.0             G      0.0            0.0            1.109629E+03   0.0            0.0            0.0
2.500000E-02    G      0.0            0.0            1.109213E+03   0.0            0.0            0.0
5.000000E-02    G      0.0            0.0            1.108986E+03   0.0            0.0            0.0
7.500000E-02    G      0.0            0.0            1.109663E+03   0.0            0.0            0.0
1.000000E-01    G      0.0            0.0            1.110218E+03   0.0            0.0            0.0
1.250000E-01    G      0.0            0.0            1.109507E+03   0.0            0.0            0.0
1.500000E-01    G      0.0            0.0            1.109184E+03   0.0            0.0            0.0
1.750000E-01    G      0.0            0.0            1.111345E+03   0.0            0.0            0.0
2.000000E-01    G      0.0            0.0            1.111682E+03   0.0            0.0            0.0
2.250000E-01    G      0.0            0.0            1.097962E+03   0.0            0.0            0.0
2.500000E-01    G      0.0            0.0            1.058320E+03   0.0            0.0            0.0
2.750000E-01    G      0.0            0.0            9.901852E+02   0.0            0.0            0.0
3.000000E-01    G      0.0            0.0            8.998873E+02   0.0            0.0            0.0
3.250000E-01    G      0.0            0.0            7.962762E+02   0.0            0.0            0.0
3.500001E-01    G      0.0            0.0            6.878726E+02   0.0            0.0            0.0
3.750001E-01    G      0.0            0.0            5.840244E+02   0.0            0.0            0.0
4.000001E-01    G      0.0            0.0            4.936776E+02   0.0            0.0            0.0
4.250001E-01    G      0.0            0.0            4.216771E+02   0.0            0.0            0.0
4.500001E-01    G      0.0            0.0            3.684155E+02   0.0            0.0            0.0
4.750001E-01    G      0.0            0.0            3.325413E+02   0.0            0.0            0.0
5.000001E-01    G      0.0            0.0            3.105166E+02   0.0            0.0            0.0
5.250000E-01    G      0.0            0.0            2.932557E+02   0.0            0.0            0.0
5.500000E-01    G      0.0            0.0            2.672145E+02   0.0            0.0            0.0
5.750000E-01    G      0.0            0.0            2.208370E+02   0.0            0.0            0.0
6.000000E-01    G      0.0            0.0            1.480881E+02   0.0            0.0            0.0
6.249999E-01    G      0.0            0.0            4.576413E+01   0.0            0.0            0.0
6.499999E-01    G      0.0            0.0           -8.817217E+01   0.0            0.0            0.0
6.749999E-01    G      0.0            0.0           -2.509008E+02   0.0            0.0            0.0
6.999999E-01    G      0.0            0.0           -4.323849E+02   0.0            0.0            0.0
7.249998E-01    G      0.0            0.0           -6.199208E+02   0.0            0.0            0.0
7.499998E-01    G      0.0            0.0           -8.038803E+02   0.0            0.0            0.0
7.749998E-01    G      0.0            0.0           -9.777825E+02   0.0            0.0            0.0
7.999998E-01    G      0.0            0.0           -1.136243E+03   0.0            0.0            0.0
8.249997E-01    G      0.0            0.0           -1.276920E+03   0.0            0.0            0.0
8.499997E-01    G      0.0            0.0           -1.403501E+03   0.0            0.0            0.0
8.749997E-01    G      0.0            0.0           -1.523771E+03   0.0            0.0            0.0
8.999997E-01    G      0.0            0.0           -1.645306E+03   0.0            0.0            0.0
9.249997E-01    G      0.0            0.0           -1.774612E+03   0.0            0.0            0.0
9.499996E-01    G      0.0            0.0           -1.917867E+03   0.0            0.0            0.0
9.749996E-01    G      0.0            0.0           -2.078544E+03   0.0            0.0            0.0
9.999996E-01    G      0.0            0.0           -2.254974E+03   0.0            0.0            0.0
1.025000E+00    G      0.0            0.0           -2.442921E+03   0.0            0.0            0.0
1.050000E+00    G      0.0            0.0           -2.639141E+03   0.0            0.0            0.0
1.075000E+00    G      0.0            0.0           -2.839497E+03   0.0            0.0            0.0
1.100000E+00    G      0.0            0.0           -3.036692E+03   0.0            0.0            0.0
1.125000E+00    G      0.0            0.0           -3.225716E+03   0.0            0.0            0.0
1.149999E+00    G      0.0            0.0           -3.410247E+03   0.0            0.0            0.0
1.174999E+00    G      0.0            0.0           -3.596073E+03   0.0            0.0            0.0
1.199999E+00    G      0.0            0.0           -3.776191E+03   0.0            0.0            0.0
```

Listing 9-3 Output for Discrete Gust Response of BAH Wing (Continued)

```
 POINT-ID =      11

                               F O R C E S   O F   S I N G L E - P O I N T   C O N S T R A I N T

    TIME        TYPE         T1              T2              T3              R1             R2             R3
 0.0              G      0.0             0.0             0.0            4.578200E+05   1.502993E+05   2.403533E+05
 2.500000E-02     G      0.0             0.0             0.0            2.287512E+05   1.726882E+05   1.929670E+05
 5.000000E-02     G      0.0             0.0             0.0           -1.919589E+05   1.331359E+05   7.908797E+04
 7.500000E-02     G      0.0             0.0             0.0           -4.963040E+03   9.903859E+04   3.334882E+04
 1.000000E-01     G      0.0             0.0             0.0            4.918563E+05   5.519221E+04   8.505019E+04
 1.250000E-01     G      0.0             0.0             0.0            1.308652E+05  -3.697446E+04   8.820973E+04
 1.500000E-01     G      0.0             0.0             0.0           -1.207049E+06  -9.517260E+04  -3.746379E+05
 1.750000E-01     G      0.0             0.0             0.0           -1.527517E+06  -1.660655E+05  -1.280005E+06
 2.000000E-01     G      0.0             0.0             0.0            3.077393E+06  -9.880904E+05   6.222305E+03
 2.250000E-01     G      0.0             0.0             0.0            1.816936E+07  -3.961293E+06   9.963644E+06
 2.500000E-01     G      0.0             0.0             0.0            4.922163E+07  -1.005450E+07   3.548669E+07
 2.750000E-01     G      0.0             0.0             0.0            9.688455E+07  -1.861299E+07   7.731285E+07
 3.000000E-01     G      0.0             0.0             0.0            1.538111E+08  -2.739754E+07   1.278717E+08
 3.250000E-01     G      0.0             0.0             0.0            2.090418E+08  -3.381135E+07   1.772224E+08
 3.500001E-01     G      0.0             0.0             0.0            2.559364E+08  -3.607156E+07   2.199131E+08
 3.750001E-01     G      0.0             0.0             0.0            2.927564E+08  -3.360202E+07   2.539551E+08
 4.000001E-01     G      0.0             0.0             0.0            3.155180E+08  -2.702201E+07   2.748986E+08
 4.250001E-01     G      0.0             0.0             0.0            3.159732E+08  -1.808489E+07   2.757133E+08
 4.500001E-01     G      0.0             0.0             0.0            2.902716E+08  -9.277473E+06   2.539533E+08
 4.750001E-01     G      0.0             0.0             0.0            2.455766E+08  -2.963214E+06   2.155412E+08
 5.000001E-01     G      0.0             0.0             0.0            1.934463E+08  -6.313372E+05   1.692089E+08
 5.250000E-01     G      0.0             0.0             0.0            1.396292E+08  -2.685184E+06   1.200098E+08
 5.500000E-01     G      0.0             0.0             0.0            8.577131E+07  -8.487236E+06   7.112842E+07
 5.750000E-01     G      0.0             0.0             0.0            3.860412E+07  -1.637795E+07   2.928766E+07
 6.000000E-01     G      0.0             0.0             0.0            9.529455E+06  -2.398121E+07   3.332158E+06
 6.249999E-01     G      0.0             0.0             0.0            3.721396E+06  -2.901301E+07  -2.917591E+06
 6.499999E-01     G      0.0             0.0             0.0            1.563199E+07  -3.006750E+07   6.952157E+06
 6.749999E-01     G      0.0             0.0             0.0            3.733358E+07  -2.682298E+07   2.715102E+07
 6.999999E-01     G      0.0             0.0             0.0            6.573027E+07  -1.989346E+07   5.397842E+07
 7.249998E-01     G      0.0             0.0             0.0            9.842066E+07  -1.076818E+07   8.380470E+07
 7.499998E-01     G      0.0             0.0             0.0            1.277767E+08  -1.638552E+06   1.101674E+08
 7.749998E-01     G      0.0             0.0             0.0            1.446556E+08   5.257225E+06   1.260394E+08
 7.999998E-01     G      0.0             0.0             0.0            1.460436E+08   8.426425E+06   1.283763E+08
 8.249997E-01     G      0.0             0.0             0.0            1.351522E+08   7.418438E+06   1.188569E+08
 8.499997E-01     G      0.0             0.0             0.0            1.157641E+08   2.688167E+06   1.009524E+08
 8.749997E-01     G      0.0             0.0             0.0            9.035278E+07  -4.500588E+06   7.787553E+07
 8.999997E-01     G      0.0             0.0             0.0            6.260421E+07  -1.220302E+07   5.297147E+07
 9.249997E-01     G      0.0             0.0             0.0            3.777444E+07  -1.834084E+07   3.033198E+07
 9.499996E-01     G      0.0             0.0             0.0            2.002437E+07  -2.143002E+07   1.400410E+07
 9.749996E-01     G      0.0             0.0             0.0            1.114935E+07  -2.087231E+07   6.330624E+06
 9.999996E-01     G      0.0             0.0             0.0            1.106438E+07  -1.684888E+07   6.784177E+06
 1.025000E+00     G      0.0             0.0             0.0            1.752344E+07  -1.031460E+07   1.252859E+07
 1.050000E+00     G      0.0             0.0             0.0            2.645404E+07  -2.972595E+06   2.056996E+07
 1.075000E+00     G      0.0             0.0             0.0            3.475611E+07   3.279618E+06   2.912948E+07
 1.100000E+00     G      0.0             0.0             0.0            4.198576E+07   7.114893E+06   3.668042E+07
 1.125000E+00     G      0.0             0.0             0.0            4.795212E+07   7.923195E+06   4.116635E+07
 1.149999E+00     G      0.0             0.0             0.0            5.043980E+07   5.593115E+06   4.180366E+07
 1.174999E+00     G      0.0             0.0             0.0            4.639060E+07   1.023708E+06   3.960902E+07
 1.199999E+00     G      0.0             0.0             0.0            3.164836E+07  -2.909778E+06   3.202975E+07
```

Transient Rolling of BAH Wing Due to Aileron (Example HA146B)

This example considers the roll response of the BAH wing due to an enforced rotation of the aileron. The Lagrange Multiplier method is used to enforce the aileron rotation discussed in Enforced Motion in the *MSC Dynamic Analysis User's Guide*. Example 8-4 of Bisplinghoff, Ashley, and Halfman (1955, pp. 467-469) [Reference 8] shows the calculation of the aileron effectiveness of the BAH wing as a function of Mach number using aerodynamic strip theory. Example HA144B (p. 240) determined the steady roll rate as an antisymmetric static aeroelastic problem. The present example solves for the steady roll rate from the time history of a single degree-of-freedom rolling maneuver by use of the dynamic aeroelastic response technique. The basic model is the same as before: the structural model is contained in the input files BAH_STRUCT.DAT (Listing 7-3), BAH_MASS.DAT (Listing 7-4), and BAH_AILERON.DAT (Listing 7-5), and the aerodynamic model is contained in the data set BAH_AERO58.DAT (Listing 7-6). Only the new or modified data are discussed below.

Main Index

The dynamic response analysis benefits from the inclusion of some structural damping, and a level of $g = 0.03$ is included in TABDMP1 2000. The fuselage GRID 11 requires additional constraints in plunge and pitch on SPC 13 but is free in roll. The aileron region of the aerodynamic model also requires a spline to connect the trailing edge region boxes on the surface SPLINE1 104 to the aileron GRIDs 8, 10, and 12 on SET1 15.

The type of dynamic excitation applied to the aileron is an enforced rotation, which is enforced by the Lagrange Multiplier method. A negative unit aileron rotation $\delta_a = -1.0 \text{ rad}$ is selected for the enforced rotation on the right wing in order to cause the wing to roll positively, that is, the right wing tip moves downward. The desired aileron rotation is obtained by applying an unknown hinge moment to the aileron. The hinge moment is introduced as an "extra" DOF, EPOINT 115 entry in the Bulk Data Section, which augments the stiffness matrix. Displacements proportional to structural loads imposed at extra points are represented by additional terms in the stiffness matrix at the intersections of columns corresponding to the structural grid points and the additional rows corresponding to the extra points. The DMIG ENFORCE entry defines this relationship in the matrix form that includes both EPOINT 115 and GRID 12, DOF R2. The matrix ENFORCE automatically augments the structural stiffness matrix via the K2PP = ENFORCE Case Control command.

The response analysis is done at the aircraft velocity of $475 \text{ mph} = 8360 \text{ in/s}$ but assuming a Mach number of 0.0 and at four reduced frequencies of 0.001, 0.02, 0.10 and 0.50 as listed on the MKAERO1 entry. The reduced frequencies cover the range of frequencies up to the assumed cut-off frequency of 10.0 Hz and includes the first four antisymmetrical vibration modes that are more than sufficient to represent the motion of a rigid body roll. The selection of Mach number 0.0 neglects compressibility effects. The AERO entry lists the velocity at 8360.0 in/s, along with the reference chord, sea-level density, and the flag for antisymmetrical aerodynamic loads. PARAM,Q selects a value of 4.00747 psi for the dynamic pressure, which corresponds to the velocity of 475 mph at sea level.

The TLOAD1 1000 entry identifies the scale factor DAREA 1001, the DELAY 1002, the time-dependent moment by the blank TYPE field, and the loading table TID 1003. DAREA 1001 specifies EPOINT 115 as the point of load application in the Lagrange Multiplier technique, and an aileron rotation scale factor of -1.0. DELAY 1002 defines a time delay of 0.2 seconds in order to observe that the response has damped out at the end of the previous period in the Fourier analysis, and to avoid having to compute the time history for a complete period.

As in the discrete gust analysis (see Example HA146A in the previous section), a square-wave time history of the forcing function is input. The rotation is enforced for 1.0 second on the aileron, then reversed for 1.0 second, and then returned to zero for the roll rate to damp out reasonably well before the next period. TABLED1 1003 provides the tabular description of the aileron input beginning with 1.0 rad for the first second and then reversing to -1.0 rad for the next second. (Note that there is no extrapolation of tabulated data in Fourier analysis, so the return of the aileron to 0.0 rad is implied beyond two seconds.) By the Lagrange Multiplier method outlined above, the moment applied at EPOINT 115 leads to the unit enforced rotation about the aileron hinge line.

The EIGR entry specifies the modified Givens eigenvalue method MGIV and requests all 12 modes to be found and normalized on the largest element. PARAM,LMODES,12 uses all 12 modes in the response calculation. The default is to use all of the modes calculated by EIGR, so LMODES is not needed, but it is included here to emphasize the requirement to have the aileron mode present in the analysis because, in this example, the aileron mode has the highest frequency. If the aileron actuator (CELAS2 3) had a lower stiffness, fewer modes could have been used.

The FREQ1 40 entry lists the equally spaced frequencies at which the Fourier analysis is performed. If a period of T = 5.0 seconds is assumed to be sufficient for the motion induced by the 2.0 sec duration aileron excitation to damp out, then the frequency interval becomes $\Delta f = \mathrm{DF} = 1/\mathrm{T} = 0.2\ \mathrm{Hz}$ and the number of equally spaced frequencies up to the assumed cutoff at 10.0 Hz becomes NDF = 50.

A response record is requested up to the reversal of the aileron input at 1.20 seconds. The Fourier analysis precedes and is independent of the output time history. The purpose of this analysis is to solve for the steady roll rate, which is found by numerical differentiation of the output time history. A sufficiently accurate derivative can be found using a time interval of $\Delta t = 0.02\ \mathrm{sec}$, so TSTEP 41 prescribes N = 60 and DT = 0.02.

Case Control Commands

The Case Control Section contains the TITLE, SUBTITLE, LABEL, and ECHO = BOTH. SPC = 13 selects some of the root constraints. MPC = 1 selects the multipoint constraint equation used to represent the control surface relative motion. METHOD = 10 selects the EIGR entry for the vibration analysis and SVEC = ALL requests the printed eigenvectors. K2PP = ENFORCE selects the DMIG entry. SDAMP = 2000 selects $g = 0.03$ for the modal damping. DLOAD = 1000 selects the hinge moment applied to the EPOINT 115. FREQ = 40 selects the frequency list. TSTEP = 41 selects the time history output request. DISP = 2 selects SET 2 for printing the physical displacements of GRIDs 11 and 12. Following OUTPUT(XYOUT) is an xy-plot request. Before the plot request are several optional statements that define the plot frame and plot titles. An XYPLOT is requested for the wing (roll) at GRID 11 about the x-axis. The BEGIN BULK command completes the Case Control Section.

The Executive Control Section identifies ID MSC, HA146B, which denotes Problem No. HA146B in the Test Problem Library. TIME 10 limits the CPU time to 10.0 minutes. SOL 146 calls for the Dynamic Aeroelastic Response DMAP sequence. The CEND statement completes the Executive Control Section.

Output

The input control and data files are shown in Listing 9-4, the sorted Bulk Data entries are in Listing 9-5. Selected output is shown in Listing 9-6 and is discussed briefly below.

The first output is the vibration frequency analysis. This is followed by the first three and the last vibration modes. The first mode is rigid body roll with a computed zero frequency. The second mode is first antisymmetric torsion and the third mode is first antisymmetric bending. The twelfth mode is the aileron rotation mode with its 60.0 Hz frequency.

The third set of output is the time history of the roll maneuver, which is also plotted in Figure 9-5 as represented by the bank angle of GRID 11, DOF R1. The history does not begin at zero because no initial conditions are imposed in the Fourier analysis and the aileron input was selected to damp to zero roll rate rather than zero bank angle. (Note, however, that the bank angle is initially relatively constant at -0.718 rad and shows the maneuver of the previous period to have damped out.) It is the roll rate that is of interest in this analysis rather than the bank angle, and the roll rate can be obtained by numerical differentiation of the bank angle time history. The roll begins at 0.2 seconds due to the delay on the TLOAD1,1000 entry. The steady roll rate (the constant slope of the bank angle versus time curve) is achieved after 1.0 sec in Figure 9-5. Numerical differentiation between $t = 1.18$ and $1.20\ \text{sec}$ gives a roll rate $p = 3.30\ \text{rad/sec}$ for the unit aileron rotation $\delta_a = 1.0\ \text{rad}$. With the velocity of $V = 8360\ \text{in/s}$ and the wing semispan of $b = 500\ \text{in}$, the steady rolling helix angle becomes $pb/2V\delta_a = 0.197$. This agrees closely with the static aeroelastic solution of Example HA144B (p. 240), which obtained $pb/2V\delta_a = 0.203$.

Figure 8-18 of Bisplinghoff, Ashley, and Halfman (1955, p. 469) [Reference 8] is reproduced in Figure 9-5 to permit a qualitative comparison between the results of the MSC Nastran dynamic Fourier transform solution, based on Lifting Surface Theory (DLM) at Mach zero, and the earlier static aeroelastic results based on Strip Theory with a Prandtl-Glauert compressibility correction. The textbook gives a $pb/2V\delta_a$ value of 0.061, which can be compared with the 0.197 value cited above. The textbook value can be approached by: reducing the effectiveness of the aileron by 61.5% to match the textbook at zero dynamic pressure and by performing the analysis at $M = 0.728$, $\bar{q} = 5.43\ \text{psf.}$ to match the textbook condition. With these changes MSC Nastran gives a steady state roll rate of 0.075.

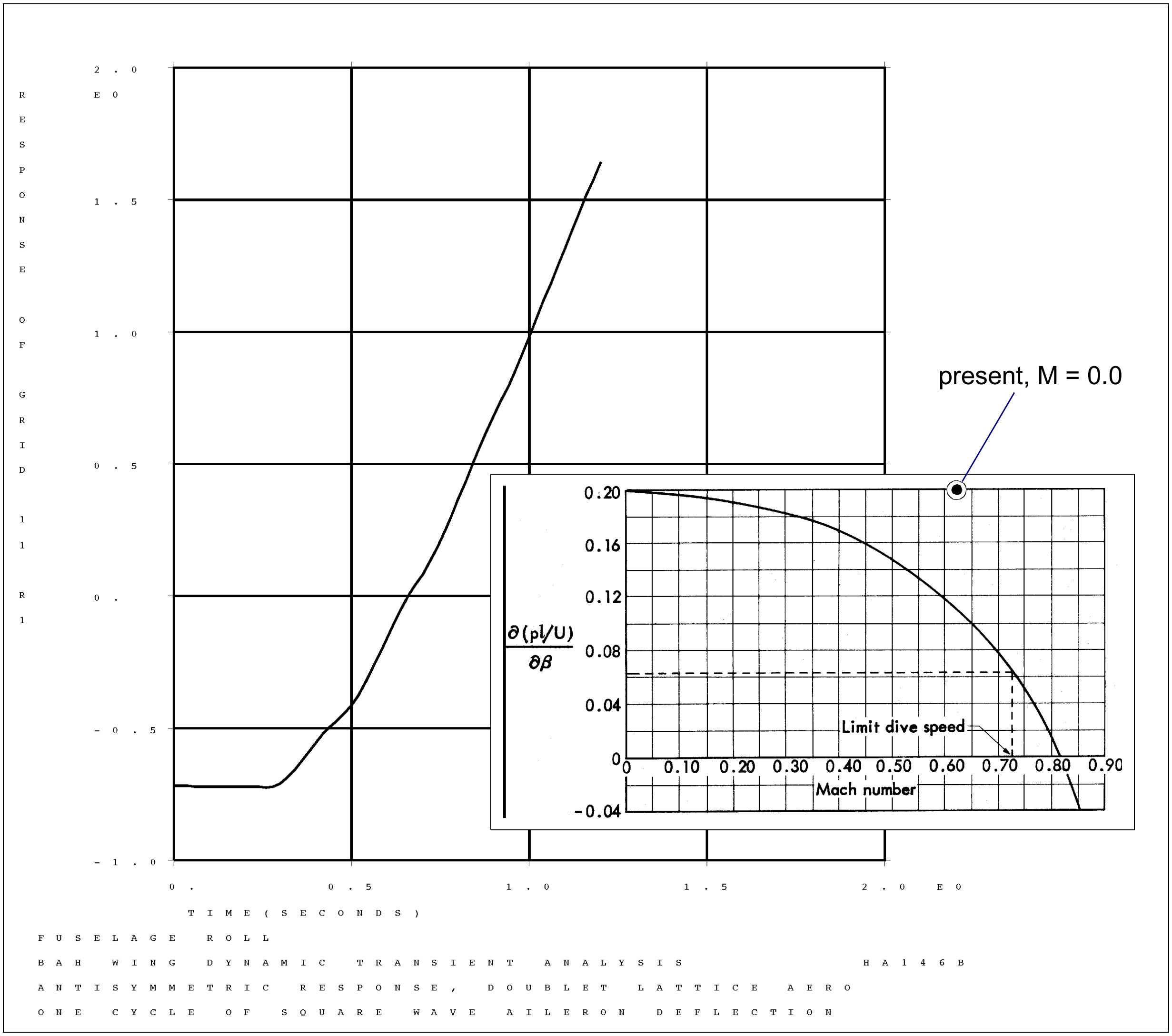


Figure 9-5 Roll Response of Fuselage Degree of Freedom. Note that the slope of the roll response curve is roll rate, p. [Inset is from Bisplinghoff, Ashley, and Halfman (1955, Figure 8-18])

Listing 9-4 Input Files for Transient Aileron Roll

```
 N A S T R A N    E X E C U T I V E    C O N T R O L    D E C K    E C H O


ID MSC,HA146B
$$$$$$$$           HANDBOOK FOR AEROELASTIC ANALYSIS EXAMPLE                   $$$$$$$$
$                                                                                     $
$       MODEL DESCRIPTION       BAH JET TRANSPORT WING EXAMPLE                        $
$                               ANTISYMMETRIC RESPONSE TO A                           $
$                               ENFORCED AILERON DEFLECTION                           $
$                                                                                     $
$       SOLUTION                TRANSIENT ANALYSIS USING                              $
$                               DOUBLET LATTICE METHOD AERODYNAMICS                   $
$                               AT MACH NO. OF 0.0                                    $
$                                                                                     $
$       OUTPUT                  XY PLOT OF FUSELAGE ROLL                              $
$                                                                                     $
$$$$$$$$                                                                        $$$$$$$
TIME  10                  $ CPU TIME IN MINUTES
SOL 146                    $ AEROELASTIC RESPONSE
CEND
```

```
BAH WING DYNAMIC TRANSIENT ANALYSIS         HA146B                                                      PAGE     2
 ANTISYMMETRIC RESPONSE, DOUBLET LATTICE AERO

 ONE CYCLE OF SQUARE WAVE AILERON DEFLECTION

                                C A S E    C O N T R O L    D E C K    E C H O
            CARD
            COUNT
             1      TITLE = BAH WING DYNAMIC TRANSIENT ANALYSIS         HA146B
             2      SUBTI = ANTISYMMETRIC RESPONSE, DOUBLET LATTICE AERO
             3      LABEL = ONE CYCLE OF SQUARE WAVE AILERON DEFLECTION
             4      ECHO = BOTH
             5        SPC = 13                 $ BOUNDARY CONDITIONS (ANTISYMMETRIC)
             6        MPC = 1                  $ CONTROL SURFACE RELATIVE MOTION
             7        METHOD = 10              $ MODIFIED-GIVENS EIGENVALUE METHOD
             8        SVEC = ALL               $ PRINT VIBRATION MODES
             9        K2PP = ENFORCE           $ EPOINT ADDED VIA DMIG
            10        SDAMP = 2000             $ STRUCTURAL DAMPING
            11        DLOAD = 1000             $ LOADING
            12        FREQ = 40                $ FREQUENCY LIST
            13        TSTEP = 41               $ SOLUTION TIME STEPS
            14      OUTPUT
            15        SET 2 = 11
            16        DISP = 2                 $ STRUCTURAL GRID POINT DISPLACEMENTS
            17      OUTPUT(XYOUT)              $ XY PLOTTING PACKAGE
            18        CSCALE 2.1
            19        PLOTTER NASTRAN
            20        CURVELINESYMBOL = 0
            21        XMIN  =    0.
            22        XMAX  =    2.0
            23        XGRID LINES = YES
            24        YGRID LINES = YES
            25        UPPER TICS = -1
            26        RIGHT TICS = -1
            27        XTITLE = TIME(SECONDS)
            28        TCURVE = FUSELAGE ROLL
            29        YTITLE = RESPONSE OF GRID 11 R1
            30      XYPLOT     DISP /  11(R1)
            31      BEGIN BULK
```

Main Index

Listing 9-4 Input Files for Transient Aileron Roll (Continued)

```
BAH WING DYNAMIC TRANSIENT ANALYSIS         HA146B                                                              PAGE     3
 ANTISYMMETRIC RESPONSE, DOUBLET LATTICE AERO

 ONE CYCLE OF SQUARE WAVE AILERON DEFLECTION

                                        I N P U T   B U L K   D A T A   D E C K   E C H O

                         .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                         INCLUDE BAH_STRUCT.DAT
                         $
                         INCLUDE BAH_MASS.DAT
                         $
                         INCLUDE BAH_AILERON
                         $
                         $        THE EPOINT ENTRY DEFINES AN "EXTRA" POINT IN THE STRUCTURAL MODEL.
                         $        THIS ONE REPRESENTS A LAGRANGE MULTIPLIER FOR THE AILERON HINGE MOMENT.
                         $
                         EPOINT  115
                         $
                         $
                         $        TABDMP1 DEFINES DAMPING COEFFICIENTS (G1) VERSES FREQUENCY (F1).
                         $        (3 PERCENT STRUCTURAL DAMPING IS SPECIFIED OVER THE ENTIRE FREQUENCY
                         $        RANGE. VALUES ARE LINEARLY INTERPOLATED AND EXTRAPOLATED. A 3
                         $        PERCENT STRUCTURAL DAMPING IS ROUGHLY EQUIVALENT TO 1.5 PERCENT
                         $        CRITICAL DAMPING).
                         $
                         $       ID      TYPE
                         TABDMP1 2000                                                            +T2000
                         $       F1      G1      F2      G2     "ENDT"
                         +T2000  0.      .03     10.     .03     ENDT
                         $
                         $                       * * CONSTRAINTS * *
                         $
                         $        THE SPC ENTRY CONSTRAINS DOFS.
                         $
                         $       SID     G       C       D
                         SPC     13      11      35
                         $
                         $* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                         $
                         $                     * * * AERODYNAMIC DATA * * *
                         $
                         $                         (LB-IN-SEC SYSTEM)
                         $
                         $                       * * ELEMENT GEOMETRY * *
                         $
                         $        THE AERO ENTRY DEFINES BASIC AERODYNAMIC PARAMETERS. ACSID IS THE
                         $        AERO COORDINATE SYSTEM. VELOCITY. REFC IS THE REFERENCE
                         $        COORDINATE SYSTEM. RHOREF IS REFERENCE DENSITY. SYMXZ AND
                         $        SYMXY ARE SYMMETRY KEYS.
                         $
                         $       ACSID   VELOCITY REFC    RHOREF  SYMXZ   SYMXY
                         AERO    1       8360.   131.232 1.1468-7-1
                         $
                         INCLUDE BAH_AERO58.DAT
                         $
                         $       PARAM,Q SPECIFIES DYNAMIC PRESSURE.
                         $
                         PARAM   Q       4.00747
                         $
                         $        THE SPLINE1 ENTRY SPECIFIES A SURFACE SPLINE FOR INTERPOLATION
                         $        OVER A REGION (BOX1 THRU BOX2) OF A CAERO PANEL AND THE
                         $        STRUCTURAL GRIDS LISTED ON A SET1 FLAGGED BY SETG.  DZ IS
                         $        A LINEAR ATTACHMENT FLEXIBLITY.
                         $
                         $       EID     CAERO   BOX1    BOX2    SETG    DZ
                         SPLINE1 104     2001    2005    2018    15
                         $
                         $        THE SET1 ENTRY DEFINES THE STRUCTURAL GRID POINTS USED FOR
                         $        INTERPOLATION BY THE SPLINE.
                         $
                         $       SID     G1      G2      G3      G4      G5      G6
                         SET1    15      8       10      12
                         $
                         $        THE MKAERO1 ENTRY DEFINES COMBINATIONS OF MACH NUMBER AND REDUCED
                         $        FREQUENCY EACH OF WHICH WILL BE USED TO GENERATE A MATRIX OF
                         $        GENERALIZED AERODYNAMIC FORCES.
                         $
                         $       M1      M2      M3      M4      ETC
                         MKAERO1 0.0                                                             +MK
                         $       K1      K2      K3      K4      ETC
                         +MK     0.001    0.02   0.10    0.50
                         $
```

Listing 9-4 Input Files for Transient Aileron Roll (Continued)

```
$* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
$
$                  * * DYNAMIC LOAD AND RESPONSE DATA * *
$
$        TLOAD1 DEFINES A TIME DEPENDENT DYNAMIC LOAD OR ENFORCED MOTION.
$        LISTED ARE THE ID, DAREA ID, DELAY ID, TYPE OF DYNAMIC EXCITATION,
$        AND TABLEDI ID.
$
$       SID     DAREA   DELAY   TYPE    TID
TLOAD1  1000    1001    1002            1003
$
$        DAREA DEFINES THE DOF WHERE THE LOAD IS APPLIED AND A SCALE FACTOR.
$
$       SID     P       C       A
DAREA   1001    115     0       -1.0
$
$        TABLED1 DEFINES A TABULAR FUNCTION OF A TIME-DEPENDENT LOAD.
$
$       SID
TABLED1 1003                                                            +T1003
$       X1      Y1      X2      Y2      ETC.
+T1003  0.      1.      1.      1.      1.      -1.     2.      -1.     +T1003A
+T1003A ENDT
$
$        THE DELAY ENTRY SPECIFIES THE GRID POINT, DISPLACEMENT COMPONENT
$        AND THE TIME DELAY OF ONSET OF THE FORCING FUNCTION.
$
$       SID     P       C       T
DELAY   1002    115     0       .2
$
$* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
$
$        * * * USER SUPPLIED DIRECT MATRIX INPUT DATA * * *
$
$        TIN=1 SPECIFIES THAT THE ELEMENTS WILL BE REAL AND SINGLE PRE-
$        CISION, TOUT=0 SPECIFIES THAT THE TYPE OF MATRIX TO BE GENERATED
$        WILL BE DETERMINED INTERNALLY, POLAR=0 SPECIFIES THAT THE INPUT
$        WILL BE IN ARGAND DIAGRAM FORM (X,IY).
$
$       NAME    "0"     IFO     TIN     TOUT    POLAR           NCOL
DMIG    ENFORCE 0       1       1       0
$
$        G2 AND C2 SPECIFY THAT A PITCHING MOMENT OF 1.0 IN LB BE APPLIED
$        AT THE HINGE-LINE OF THE AILERON.  SEE P. 3.5-9 OF THE "HANDBOOK
$        FOR DYNAMIC ANALYSIS" FOR A DISCUSSION OF LAGRANGE MULTIPLIERS.
$        THE MINUS SIGN ARISES FROM THE DEFINITION OF A POSITIVE AILERON
$        DEFLECTION, that is, TRAILING EDGE DOWN ON THE STARBOARD WING.
$
$       NAME    G1      C1              G2      C2      X21
DMIG    ENFORCE 12      5               115     0       1.
$
$       NAME    G2      C2      X22     G1      C1      X12
DMIG    ENFORCE 115     0               12      5       -1.
$
$        EIGR DEFINES EIGENVALUE EXTRACTION DATA.  LISTED ARE THE
$        EIGENVALUE EXTRACTION METHOD, FREQUENCY RANGE, NUMBER OF
$        EXPECTED AND DESIRED ROOTS AND THE METHOD OF NORMALIZATION.
$
$       SID     METHOD  F1      F2      NE      ND
EIGR    10      MGIV                            12                      +EIGR
$       NORM
+EIGR   MAX
$
$        THE PARAM,LMODES,N ENTRY SPECIFIES THAT N MODES ARE TO BE
$        USED IN THE DYNAMIC RESPONSE ANALYSIS.
$
PARAM   LMODES  12
$
$        FREQ1 DEFINES THE SET OF FREQUENCIES USED TO OBTAIN
$        THE FREQUENCY RESPONSE SOLUTION. LISTED ARE THE STARTING
$        FREQUENCY, FREQUENCY INCREMENT AND NUMBER OF INCREMENTS.
$
$       SID     F1      DF      NDF
FREQ1   40      0.      .2      50
$
$        TSTEP DEFINES TIME STEP INTERVALS AT WHICH THE TRANSIENT
$        RESPONSES ARE DESIRED.  LISTED ARE  THE NUMBER OF STEPS,
$        THE TIME INTERVAL AND SKIP FACTOR FOR OUTPUT.
$
$       SID     N       DT      NO
TSTEP   41      60      .02     1
$
ENDDATA

INPUT BULK DATA ENTRY COUNT =      443
```

Listing 9-5 Sorted Bulk Data Entries for Transient Aileron Roll

```
BAH WING DYNAMIC TRANSIENT ANALYSIS         HA146B                                                          PAGE    12
 ANTISYMMETRIC RESPONSE, DOUBLET LATTICE AERO
 ONE CYCLE OF SQUARE WAVE AILERON DEFLECTION

                                            S O R T E D   B U L K   D A T A   E C H O

            CARD
            COUNT        .  1  ..  2  ..  3  ..  4  ..  5  ..  6  ..  7  ..  8  ..  9  .. 10  .
               1-        AEFACT  1       0.      .09     .21     .33     .45     .56     .66     +AE1
               2-        +AE1    .74
               3-        AEFACT  2       .74     .82     .90     .974
               4-        AEFACT  3       .974    1.00
               5-        AEFACT  4       0.      .1875   .375    .625    .750    .875    1.00
               6-        AERO    1       8360.   131.232 1.1468-7-1
               7-        CAERO1  1001    1000    0               5       1               1       +CA1
               8-        +CA1    78.75   0.      0.      225.    35.     500.    0.      100.
               9-        CAERO1  2001    1000    0                       2       4       1       +CA2
              10-        +CA2    78.75   0.      0.      225.    35.     500.    0.      100.
              11-        CAERO1  3001    1000    0               5       3               1       +CA3
              12-        +CA3    78.75   0.      0.      225.    35.     500.    0.      100.
              13-        CELAS2  3       5142661.12      5
              14-        CMASS2  121     5248.7  1       3
              15-        CMASS2  122     134.9   1       3       2       3
              16-        CMASS2  123     790.3   2       3
              17-        CMASS2  341     9727.   3       3
              18-        CMASS2  342     11005.  3       3       4       3
              19-        CMASS2  343     473.    4       3
              20-        CMASS2  561     3253.6  5       3
              21-        CMASS2  562     -139.7  5       3       6       3
              22-        CMASS2  563     946.3   6       3
              23-        CMASS2  781     2617.8  7       3
              24-        CMASS2  782     21.     7       3       8       3
              25-        CMASS2  783     782.3   8       3
              26-        CMASS2  9101    494.8   9       3
              27-        CMASS2  9102    -7.3    9       3       10      3
              28-        CMASS2  9103    185.2   10      3
              29-        CONM1   1       11                                                      +51
              30-        +51     17400.                          4.37+7                          +52
              31-        +52             4.35+09
              32-        CONM1   2       12                                                      +AIL1
              33-        +AIL1   0.0                                                     0.0     +AIL2
              34-        +AIL2           13970.5
              35-        CORD2R  1               0.      0.      0.      0.      0.      -1.     +C1
              36-        +C1     -1.     0.      0.
              37-        DAREA   1001    115     0       -1.0
              38-        DELAY   1002    115     0       .2
              39-        DMIG    ENFORCE 0       1       1       0
              40-        DMIG    ENFORCE 12      5               115     0       1.
              41-        DMIG    ENFORCE 115     0               12      5       -1.
              42-        EIGR    10      MGIV                            12                      +EIGR
              43-        +EIGR   MAX
              44-        EPOINT  115
              45-        FREQ1   40      0.      .2      50
              46-        GENEL   432             1       3       2       3       3       3       +01
              47-        +01     4       3       5       3       6       3       7       3       +02
              48-        +02     8       3       9       3       10      3                       +03
              49-        +03     UD              11      3       11      4       11      5       +04
              50-        +04     11      6                                                       +05
              51-        +05     Z       8.7172-61.3361-61.2778-56.2720-61.6251-51.0492-52.0478-5+06
              52-        +06     1.5630-52.4285-52.0403-53.0861-56.2720-63.2297-51.0492-53.3529-5+07
              53-        +07     1.5630-53.5021-52.0257-53.5785-52.7732-51.5726-54.8255-53.7628-5+08
              54-        +08     7.3284-56.4338-59.5810-58.8378-56.3749-53.7628-58.0136-56.4338-5+09
              55-        +09     1.0012-48.8378-51.1811-41.2758-41.1344-41.9350-41.8160-42.5283-4+10
              56-        +10     2.4294-41.6999-41.8160-42.2920-42.4294-42.8249-43.6862-43.5052-4+11
              57-        +11     5.2675-45.1171-44.2292-45.1171-45.7187-48.4840-48.2340-49.2340-4+12
              58-        +12     S       1.0     90.0    -20.25  45.0    1.0     90.0    81.0    +13
              59-        +13     45.0    1.0     186.0   -17.85  141.0   1.0     186.0   71.4    +14
              60-        +14     141.0   1.0     268.0   -15.80  223.0   1.0     268.0   63.2    +15
              61-        +15     223.0   1.0     368.0   -13.30  323.0   1.0     368.0   53.2    +16
              62-        +16     323.0   1.0     458.0   -11.05  413.0   1.0     458.0   44.2    +17
              63-        +17     413.0
              64-        GRID    1               20.25   90.                     12456
              65-        GRID    2               -81.    90.                     12456
              66-        GRID    3               17.85   186.                    12456
              67-        GRID    4               -71.4   186.                    12456
              68-        GRID    5               15.8    268.                    12456
              69-        GRID    6               -63.2   268.                    12456
              70-        GRID    7               13.3    368.                    12456
```

Listing 9-5 Sorted Bulk Data Entries for Transient Aileron Roll (Continued)

```
     71-        GRID    8               -53.2   368.                    12456
     72-        GRID    9               11.05   458.                    12456
     73-        GRID    10              -44.2   458.                    12456
     74-        GRID    11              0.0     0.                      126
     75-        GRID    12              -86.45  368.                    1246
     76-        MKAERO1 0.0                                                             +MK
     77-        +MK     0.001   0.02    0.10    0.50
     78-        MPC     1       12      3       -1.0    8       3       1.5             +MPC1
     79-        +MPC1           7       3       -0.5    12      5       33.25
     80-        PAERO1  1000
     81-        PARAM   GRDPNT  11
     82-        PARAM   LMODES  12
     83-        PARAM   Q       4.00747
     84-        PARAM   WTMASS  .0025907
     85-        SET1    14      1       THRU    11
     86-        SET1    15      8       10      12
     87-        SPC     13      11      35
     88-        SPLINE1 104     2001    2005    2018    15
     89-        SPLINE2 101     1001    1001    1035    14      0.      1.      0       +SP1
     90-        +SP1    -1.0    -1.0
     91-        SPLINE2 102     2001    2001    2016    14      0.      1.      0       +SP2
     92-        +SP2    -1.0    -1.0
     93-        SPLINE2 103     3001    3001    3005    14      0.      1.      0       +SP3
     94-        +SP3    -1.0    -1.0
     95-        TABDMP1 2000                                                            +T2000
     96-        +T2000  0.      .03     10.     .03     ENDT
     97-        TABLED1 1003                                                            +T1003
     98-        +T1003  0.      1.      1.      1.      1.      -1.     2.      -1.     +T1003A
     99-        +T1003A ENDT
    100-        TLOAD1  1000    1001    1002            1003
    101-        TSTEP   41      60      .02     1
                ENDDATA

          TOTAL COUNT=       102
```

Listing 9-6 Output for Transient Aileron Roll

```
BAH WING DYNAMIC TRANSIENT ANALYSIS         HA146B                                                              PAGE    19
 ANTISYMMETRIC RESPONSE, DOUBLET LATTICE AERO

 ONE CYCLE OF SQUARE WAVE AILERON DEFLECTION

                                               R E A L   E I G E N V A L U E S
MODE    EXTRACTION      EIGENVALUE            RADIANS             CYCLES            GENERALIZED         GENERALIZED
 NO.       ORDER                                                                       MASS              STIFFNESS
   1         1       -6.892265E-13        8.301967E-07        1.321299E-07        1.667624E+01       -1.149371E-11
   2         2        4.945913E+02        2.223941E+01        3.539512E+00        4.167461E+01        2.061190E+04
   3         3        8.508833E+02        2.916990E+01        4.642534E+00        7.082290E+00        6.026202E+03
   4         4        4.434137E+03        6.658932E+01        1.059802E+01        5.831286E+00        2.585672E+04
   5         5        8.732797E+03        9.344943E+01        1.487294E+01        4.022015E+00        3.512344E+04
   6         7        1.501493E+04        1.225354E+02        1.950212E+01        1.220782E+02        1.832996E+06
   7         9        1.766970E+04        1.329274E+02        2.115605E+01        3.908876E+00        6.906864E+04
   8         8        2.409598E+04        1.552288E+02        2.470543E+01        3.522202E+00        8.487088E+04
   9        11        4.211864E+04        2.052283E+02        3.266309E+01        3.142603E+00        1.323622E+05
  10        10        6.020845E+04        2.453741E+02        3.905250E+01        1.016245E+00        6.118652E+04
  11         6        9.304316E+04        3.050298E+02        4.854699E+01        8.852293E+00        8.236453E+05
  12        12        1.420885E+05        3.769462E+02        5.999286E+01        3.619337E+01        5.142661E+06

 EIGENVALUE = -6.892265E-13
     CYCLES =  1.321299E-07         R E A L   E I G E N V E C T O R   N O .          1

 POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
        1      G                                     1.965065E-01
        2      G                                     1.965065E-01
        3      G                                     4.061135E-01
        4      G                                     4.061135E-01
        5      G                                     5.851529E-01
        6      G                                     5.851529E-01
        7      G                                     8.034934E-01
        8      G                                     8.034934E-01
        9      G                                     1.000000E+00
       10      G                                     1.000000E+00
       11      G                                                    2.183406E-03
       12      G                                                                   0.0

 EIGENVALUE =  4.945913E+02
     CYCLES =  3.539512E+00         R E A L   E I G E N V E C T O R   N O .          2

 POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
        1      G                                    -1.785428E-01
        2      G                                     4.261678E-01
        3      G                                    -2.829573E-01
        4      G                                     8.086762E-01
        5      G                                    -1.618382E-01
        6      G                                     8.397149E-01
        7      G                                     4.125781E-02
        8      G                                     9.189913E-01
        9      G                                     2.618429E-01
       10      G                                     1.000000E+00
       11      G                                                   -5.834532E-04
       12      G                                                                   0.0

 EIGENVALUE =  8.508833E+02
     CYCLES =  4.642534E+00         R E A L   E I G E N V E C T O R   N O .          3

 POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
        1      G                                    -2.061499E-01
        2      G                                    -2.630347E-01
        3      G                                    -2.729964E-01
        4      G                                    -3.807691E-01
        5      G                                    -5.540806E-02
        6      G                                    -1.530691E-01
        7      G                                     4.391988E-01
        8      G                                     3.594076E-01
        9      G                                     1.000000E+00
       10      G                                     9.392283E-01
       11      G                                                   -2.339169E-03
       12      G                                                                   0.0
```

Listing 9-6 Output for Transient Aileron Roll (Continued)

```
 EIGENVALUE =  1.420885E+05
     CYCLES =  5.999286E+01        R E A L   E I G E N V E C T O R   N O .        12

 POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
        1      G                                      0.0
        2      G                                      0.0
        3      G                                      0.0
        4      G                                      0.0
        5      G                                      0.0
        6      G                                      0.0
        7      G                                      0.0
        8      G                                      0.0
        9      G                                      0.0
       10      G                                      0.0
       11      G                                                     0.0
       12      G                                                                   1.000000E+00

 POINT-ID =       11
                                               D I S P L A C E M E N T   V E C T O R

  TIME       TYPE          T1             T2             T3             R1             R2             R3
   0.0              G      0.0            0.0            0.0           -7.184407E-01   0.0            0.0
   2.000000E-02     G      0.0            0.0            0.0           -7.183016E-01   0.0            0.0
   4.000000E-02     G      0.0            0.0            0.0           -7.187638E-01   0.0            0.0
   6.000000E-02     G      0.0            0.0            0.0           -7.193694E-01   0.0            0.0
   8.000000E-02     G      0.0            0.0            0.0           -7.196903E-01   0.0            0.0
   1.000000E-01     G      0.0            0.0            0.0           -7.199214E-01   0.0            0.0
   1.200000E-01     G      0.0            0.0            0.0           -7.205878E-01   0.0            0.0
   1.400000E-01     G      0.0            0.0            0.0           -7.216198E-01   0.0            0.0
   1.600000E-01     G      0.0            0.0            0.0           -7.220712E-01   0.0            0.0
   1.800000E-01     G      0.0            0.0            0.0           -7.211820E-01   0.0            0.0
   2.000000E-01     G      0.0            0.0            0.0           -7.196965E-01   0.0            0.0
   2.200000E-01     G      0.0            0.0            0.0           -7.195845E-01   0.0            0.0
   2.400000E-01     G      0.0            0.0            0.0           -7.218282E-01   0.0            0.0
   2.600000E-01     G      0.0            0.0            0.0           -7.242953E-01   0.0            0.0
   2.800000E-01     G      0.0            0.0            0.0           -7.221243E-01   0.0            0.0
   3.000000E-01     G      0.0            0.0            0.0           -7.107134E-01   0.0            0.0
   3.200000E-01     G      0.0            0.0            0.0           -6.887337E-01   0.0            0.0
   3.400000E-01     G      0.0            0.0            0.0           -6.585693E-01   0.0            0.0
   3.600000E-01     G      0.0            0.0            0.0           -6.242192E-01   0.0            0.0
   3.800001E-01     G      0.0            0.0            0.0           -5.890207E-01   0.0            0.0
   4.000001E-01     G      0.0            0.0            0.0           -5.550677E-01   0.0            0.0
   4.200001E-01     G      0.0            0.0            0.0           -5.237980E-01   0.0            0.0
   4.400001E-01     G      0.0            0.0            0.0           -4.959850E-01   0.0            0.0
   4.600001E-01     G      0.0            0.0            0.0           -4.706734E-01   0.0            0.0
   4.800001E-01     G      0.0            0.0            0.0           -4.445662E-01   0.0            0.0
   5.000001E-01     G      0.0            0.0            0.0           -4.132899E-01   0.0            0.0
   5.200001E-01     G      0.0            0.0            0.0           -3.738612E-01   0.0            0.0
   5.400001E-01     G      0.0            0.0            0.0           -3.261797E-01   0.0            0.0
   5.600001E-01     G      0.0            0.0            0.0           -2.723936E-01   0.0            0.0
   5.800000E-01     G      0.0            0.0            0.0           -2.152457E-01   0.0            0.0
   6.000000E-01     G      0.0            0.0            0.0           -1.572284E-01   0.0            0.0
   6.200000E-01     G      0.0            0.0            0.0           -1.008229E-01   0.0            0.0
   6.400000E-01     G      0.0            0.0            0.0           -4.846819E-02   0.0            0.0
   6.600000E-01     G      0.0            0.0            0.0           -1.387435E-03   0.0            0.0
   6.799999E-01     G      0.0            0.0            0.0            4.169792E-02   0.0            0.0
   6.999999E-01     G      0.0            0.0            0.0            8.425930E-02   0.0            0.0
   7.199999E-01     G      0.0            0.0            0.0            1.299640E-01   0.0            0.0
   7.399999E-01     G      0.0            0.0            0.0            1.808141E-01   0.0            0.0
   7.599999E-01     G      0.0            0.0            0.0            2.370085E-01   0.0            0.0
   7.799999E-01     G      0.0            0.0            0.0            2.980180E-01   0.0            0.0
   7.999998E-01     G      0.0            0.0            0.0            3.631130E-01   0.0            0.0
   8.199998E-01     G      0.0            0.0            0.0            4.307511E-01   0.0            0.0
   8.399998E-01     G      0.0            0.0            0.0            4.981631E-01   0.0            0.0
   8.599998E-01     G      0.0            0.0            0.0            5.624685E-01   0.0            0.0
   8.799998E-01     G      0.0            0.0            0.0            6.225913E-01   0.0            0.0
   8.999997E-01     G      0.0            0.0            0.0            6.799052E-01   0.0            0.0
   9.199997E-01     G      0.0            0.0            0.0            7.367909E-01   0.0            0.0
   9.399997E-01     G      0.0            0.0            0.0            7.947523E-01   0.0            0.0
   9.599997E-01     G      0.0            0.0            0.0            8.541449E-01   0.0            0.0
   9.799997E-01     G      0.0            0.0            0.0            9.153894E-01   0.0            0.0
   9.999996E-01     G      0.0            0.0            0.0            9.795661E-01   0.0            0.0
   1.020000E+00     G      0.0            0.0            0.0            1.047222E+00   0.0            0.0
   1.040000E+00     G      0.0            0.0            0.0            1.116904E+00   0.0            0.0
   1.060000E+00     G      0.0            0.0            0.0            1.185737E+00   0.0            0.0
   1.080000E+00     G      0.0            0.0            0.0            1.251923E+00   0.0            0.0
   1.100000E+00     G      0.0            0.0            0.0            1.316347E+00   0.0            0.0
   1.120000E+00     G      0.0            0.0            0.0            1.381208E+00   0.0            0.0
   1.140000E+00     G      0.0            0.0            0.0            1.447247E+00   0.0            0.0
   1.159999E+00     G      0.0            0.0            0.0            1.513113E+00   0.0            0.0
   1.179999E+00     G      0.0            0.0            0.0            1.577945E+00   0.0            0.0
   1.199999E+00     G      0.0            0.0            0.0            1.643943E+00   0.0            0.0
```

Random Gust Response of BAH Wing (Example HA146C)

This example shows the BAH wing of Example HA146A (p. 650) responding to a random, rather than discrete, gust. Because atmospheric turbulence is a continuous random phenomenon, it is more appropriately analyzed by a statistical approach instead of the deterministic approach of the discrete gust idealization.

In this example, only the loading is changed from Example HA146A (p. 650). Therefore, the same structural and aerodynamic models are used with the vehicle again free to translate vertically without pitching. The new loading data entries are discussed below.

The purpose of the analysis is to determine the power spectral density (PSD) function of the root bending moment of the BAH wing at 475 mph at sea level, as has been done by Bisplinghoff, Ashley, and Halfman (1955, p. 691 [Reference 8]) using Strip Theory and the empirical power spectrum of atmospheric turbulence defined by

$$\phi\left(\frac{\omega}{V}\right) = \frac{0.060}{0.000004 + \left(\frac{\omega}{V}\right)^2}\frac{(\text{ft/s})^2}{\text{rad/ft}} \tag{9-1}$$

in which V is in ft/s, and in this example $V = 475\ \text{mph} = 696.67\ \text{ft/s}$. This spectrum results in a mean square gust velocity of

$$\overline{w_G^2} = \int_0^\infty \phi\left(\frac{\omega}{V}\right) d\left(\frac{\omega}{V}\right) = 15\pi = 47.12(\text{ft/s})^2 \tag{9-2}$$

MSC Nastran requires frequencies to be measured in Hertz. It is convenient to factor out the mean square gust velocity, so the spectrum is rewritten [by multiplying (9-1) by $2\pi\overline{w_G^2}/15\pi V$]

$$S_a(f) = \frac{\overline{w_G^2}}{V}\frac{0.008}{0.000004 + \left(\frac{2\pi f}{V}\right)^2} \tag{9-3}$$

The coefficient of $\left(\overline{w_G^2}/V\right)$ in (9-3) is the spectrum input into MSC Nastran; $\overline{w_G^2}$ is input on the RANDPS entry, and 1/V is input on the GUST entry. The spectrum $S_a(f)$ has units of 1/Hz, and its mean square value should be unity although it will be less because of the truncation error in the integral of (9-3) due to the finite cutoff frequency. Note that in MSC Nastran

$$\overline{w_G^2} = \int_0^{f_{co}} S_a(f)df \tag{9-4}$$

where f_{co} is the cutoff frequency.

Because this empirical gust spectrum is not a standard form in MSC Nastran (the Dryden and von Kármán forms are standard and are specified via the TABRNDG entry), it must be input in the tabular format using TABRND1. This input provides the frequency content of the gust for the random analysis in a format similar to that of the gust profile provided for the gust time history of the discrete gust transient analysis.

The GUST 3002 entry specifies some of the gust characteristics. The DLOAD field refers to the RLOAD1 3002 entry, the scale factor (angle of attack) of the gust WG (gust velocity/forward velocity) is set to 1.0/V for an assumed unit gust velocity amplitude, the reference station for the gust X0 does not apply in this frequency response analysis and is selected as 0.0. The velocity is 8360 in/s. The RLOAD1 3002 entry refers to the DAREA 3003 entry that is a required entry although its scale factor is not used in the gust analysis (see Remark 5 on DAREA entry); however, in this case DAREA is used to apply the spectrum to an EPOINT for the special purpose discussed below. The RLOAD1 entry also refers to the TABLED1 3004, which provides the unit gust frequency response up to the cutoff frequency of 10.0 Hz.

Random Response

The RANDPS 1031 entry specifies the PSD for the random analysis called out by the command RANDOM = 1031 in the Case Control section. MSC Nastran Random Analysis permits subcases for different excited (J) and applied (K) load sets, but for the gust analysis only an auto spectral density is available so the $J = K = 1$ on the RANDPS entry. It selects the TABRDN1 1032 entry that defines the PSD of the source (the gust) with a unit real coefficient $\overline{w_G^2} = X + iY = 1.0 + i0.0$. The PSD of the gust is defined in a tabular format with frequencies ranging from 0.0 to the cutoff at $f_{co} = 10.0\text{ Hz}$.

The MKAERO1 entry selects the Mach numbers and reduced frequencies used in generating the aerodynamic matrices. The Mach number is 0.62 and the reduced frequencies, $k = 0.001$, 0.02, 0.10, and 0.50, are selected to cover the range of vibration frequencies up to 10.0 Hz.

The PARAM,GUSTAERO,-1 entry is required to obtain the aerodynamic loads for the one-dimensional harmonic gust field in addition to the aerodynamic loads caused by the vibrating structure. When there are no gust loads, neither the PARAM,GUSTAERO nor the GUST entry are required. SOL 146 also requires the flight condition data of Mach number and dynamic pressure as parameters: PARAM,MACH,0.62 and PARAM,Q,4.000747.

The EIGR entry selects the GIVENS method (GIV) for determining the 11 vibration modes used in the modal formulation. These modes are the same modes selected and discussed in the discrete gust Example HA146A.

The BAH wing is free to plunge vertically, and this degree of freedom results in a frequency response to the harmonic gust field that should be zero at zero frequency. This limit cannot be achieved in MSC Nastran for numerical reasons, so the lower frequency is selected as 0.001 Hz on the FREQ 40 entry. The remaining frequencies are equally spaced, as is recommended in the Fourier solution, using the FREQ1 40 entry that selects 79 equally spaced frequencies with an interval of $\Delta f = 0.125\text{ Hz}$ from $f = 0.125$ up to 10.0Hz.

The turbulence PSD selected for the random response analysis is not automatically output by MSC Nastran, and a number of additional entries are required. An extra point EPOINT 50 is introduced and incorporated into the stiffness matrix by means of a DMIG entry. The DMIG STIFF entry adds a value of 1.0 to the structural stiffness matrix and represents the stiffness at the extra point. EPOINT 50 is independent of and not connected to the rest of the model. Its ID must be selected less than the lowest numbered CAERO entry, that is, 1001. A unit load amplitude for all frequencies is applied to EPOINT 50 by means of RLOAD1 3002 and of DAREA 3003, which selects EPOINT 50 as the degree of freedom loaded by the unit loading condition in TABLED1 3004. This results in a unit displacement for EPOINT 50. This technique can also be used to output the conventional MSC Nastran gust PSDs that may be selected on the TABRNDG entry. The ENDDATA entry completes the Bulk Data Section.

Case Control Commands

The Case Control Section contains the TITLE, SUBTITLE, and LABEL commands. ECHO = BOTH echoes back all of the Bulk Data in annotated and sorted formats. SPC = 14 selects the symmetric boundary condition. METHOD = 10 selects the ElGR entry for determining the vibration modes. SDAMP = 2000 selects the modal damping. FREQ = 40 selects the frequency set for which the frequency response calculations are performed. RANDOM = 1031 specifies that this is a random analysis and refers to the RANDPS entry. K2PP = STIFF refers to the DMlG entry with the same name and specifies that the EPOINT 50 augment the stiffness matrix. OUTPUT heads the requests for print and plot data. The SDISP(PLOT) = 1 and DlSP(PLOT) = 1 specifies the displacements to be determined for EPOINT 50; both of these requests are necessary to print and plot the power spectrum of the gust. SPCF(PHASE) = 3, SET 3 = 11 causes the magnitude and phase of the constraint forces to be generated.

SUBCASE 1 is the only loading condition and is referenced by the Bulk Data entry RANDPS 1031. The GUST = 3002 command identifies the gust and the DLOAD = 3002 command selects RLOAD1 3002, which applies the unit load to EPOINT 50.

Following the OUTPUT(XYOUT) command are the xy-output requests. (The user is referred to Section 13.3 of the *MSC Nastran Reference Guide* for xy-output.) Preceding the first xy-output request are several optional statements that define the plot frames and titles. Then, xy-plots are requested for the wing root bending moment with the magnitude and phase on the same page by XYPLOT SPCF/11(R3RM,R3IP). The next xy-output request is for the print and plot of the PSD for the wing root bending moment by XYPRINT,XYPLOT SPCF PSDF/11(R3). The last two xy-output requests are for the print and plot of the displacement PSD for EPOINT 50 by XYPRINT,XYPLOT SDISP PSDF/50(T1)and XYPRINT,XYPLOT DISP PSDF/50(T1). Both requests are necessary to obtain the desired PSD check. This generates the PSD of the atmospheric turbulence as input on the TABRND1 entry. However, this technique leads to a number of user warning messages from the PLOT module indicating that some plots are not generated. These messages can safely be ignored. The BEGIN BULK command completes the Case Control Section.

The Executive Control Section begins with the identification ID MSC, HA146C, which denotes Problem No. HA146C in the Test Problem Library. TIME 10 limits the CPU time to 10.0 minutes. SOL 146 calls for the Dynamic Aeroelastic Response DMAP sequence. The CEND statement completes the Executive Control Section.

Output

The input data are shown in Listing 9-7 followed by the sorted Bulk Data entries in Listing 9-8. Selected items in the printed output are shown in Listing 9-9. The requested xy-plots are shown in the Figure 9-6 through Figure 9-9.

The first output listed is the symmetric vibration analysis. All 11 modes are calculated for formulating the modal matrices. They are the rigid body plunge mode and the 10 elastic modes.

Next is the XY-OUTPUT SUMMARY for the input PSDF. The curve ID is 50(3) referring to EPOINT 50, component 3; the component 3 corresponds to the 50(T1) request according to the Item Code in Plotting (p. 467) in the *MSC Nastran Reference Guide*. The summary includes the RMS value of 0.995306 and the mean frequency of zero crossings N0 = 1.177425 Hz. The RMS value should be unity, as discussed above, but is slightly less because of the 10.0 Hz cutoff frequency.

The third output shown is the input power spectrum, again labeled Curve ID = 50, component 3. This is the input on TABRND1 1032 except for the initial interpolated value at $f = 0.001 \text{ Hz}$. The input PSDF is also plotted in Figure 9-6.

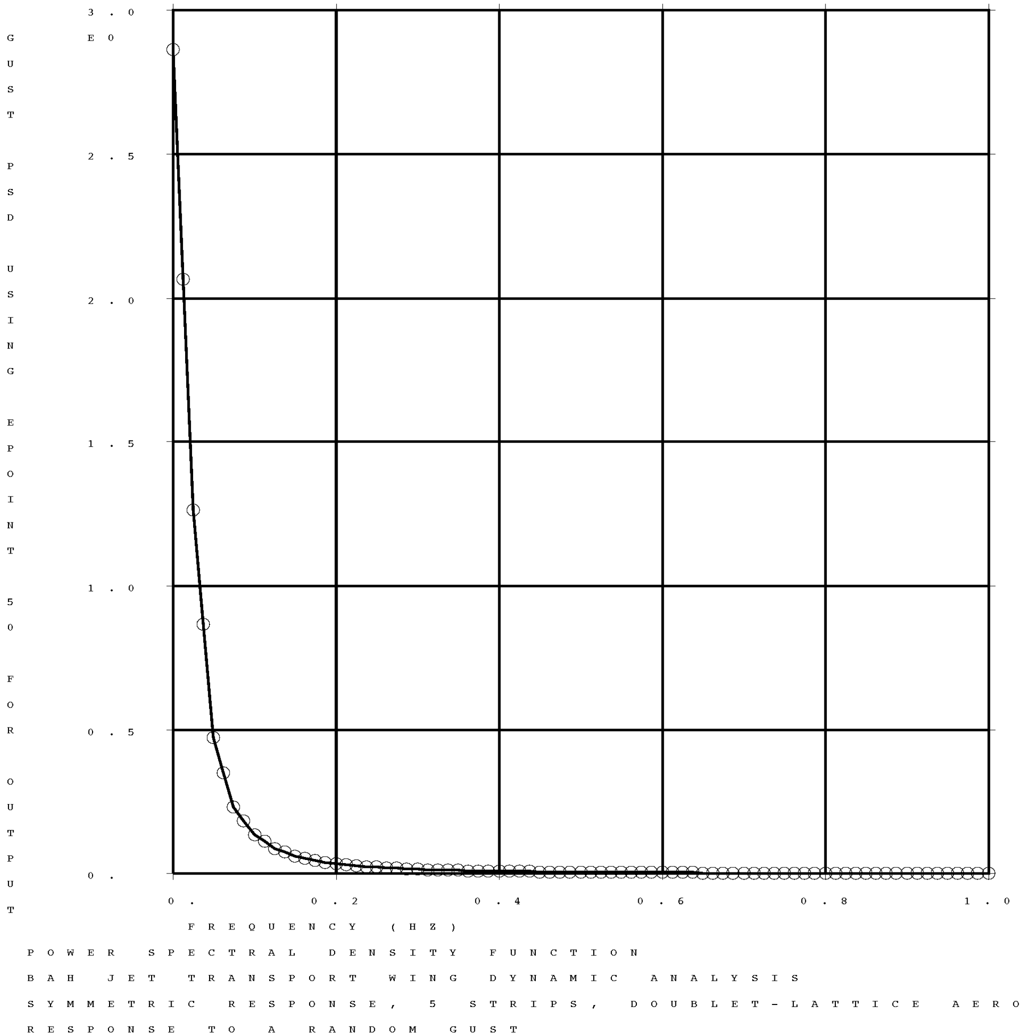


Figure 9-6 Power Spectral Density Function of Gust [(9-3)]

The COMPLEX FORCES OF SINGLE POINT CONSTRAINT output is the frequency response of the constraint forces at GRID 11 due to the gust and is printed next. The constraint forces are presented in polar format as magnitude and phase. GRID 11 degree of freedom R3 is a nonstandard degree of freedom as defined by the GENEL element and represents the wing root bending moment at the side of the fuselage. (Note: GRID 11, R1 is the bending moment at the airplane centerline, and GRID 11, R2 is the root torque.) The magnitude and phase of the wing root bending moment are plotted in the split frames of Figure 9-7.

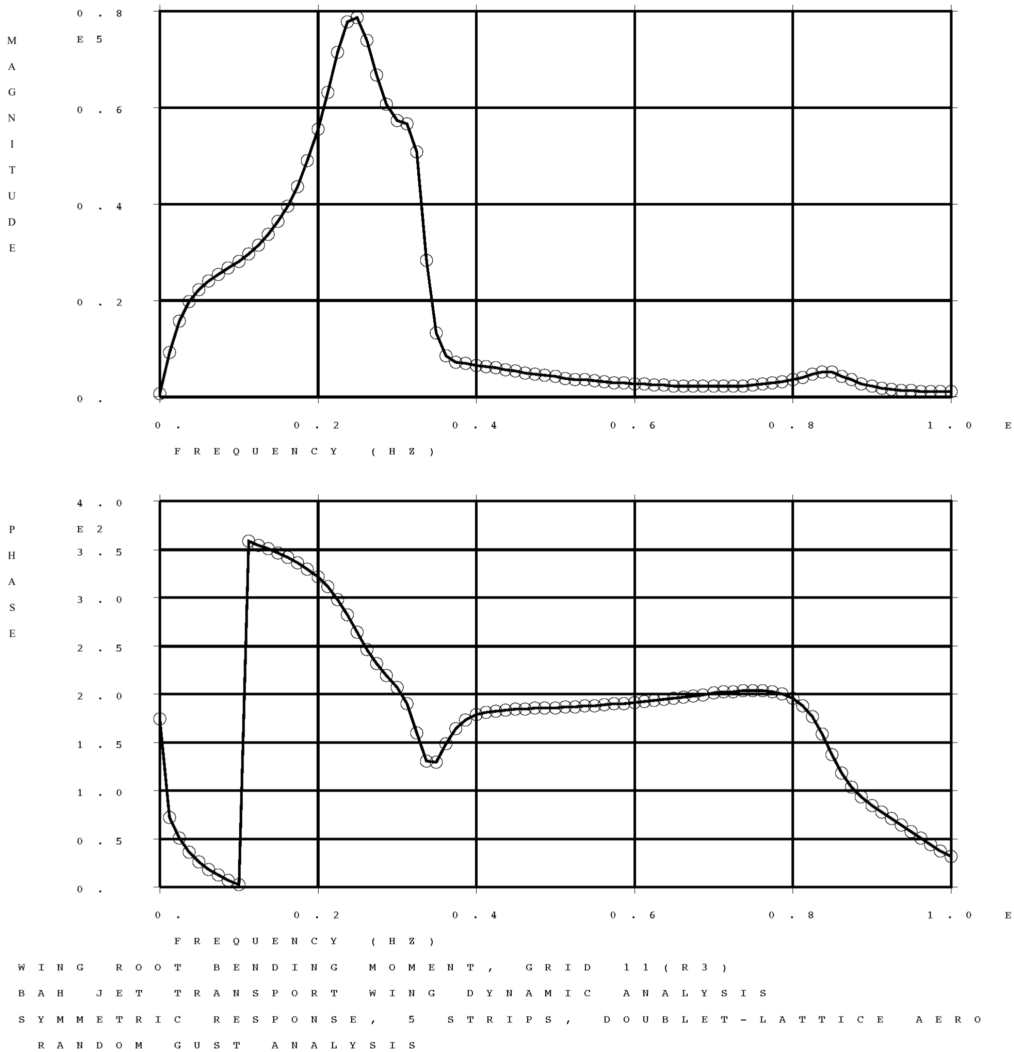


Figure 9-7 Magnitude and Phase of Wing Root Bending Moment

The next XY-OUTPUT SUMMARY is for Curve ID 11(8), which is the Item Code for degree of freedom R3 (see Plotting (p. 467) in the *MSC Nastran Reference Guide*). The RMS value of the root bending moment is 20,501.9 in-lb for the unit gust rms velocity $\bar{w}_G$, and the mean frequency of zero crossings is

$$N_0 = 1.620235 \text{ Hz}.$$

The last printed output is the PSDF of the root bending moment. It is also plotted along with results obtained from a textbook, in Figure 9-8.

The frequency response of the mean square root bending moment here is obtained by rerunning this example with the input PSDF in TABRND1 1032 changed to a unit spectrum. Then the output PSDF is the desired frequency response function, that is, the mean square of the root bending moment and is plotted along with textbook results, in Figure 9-9.

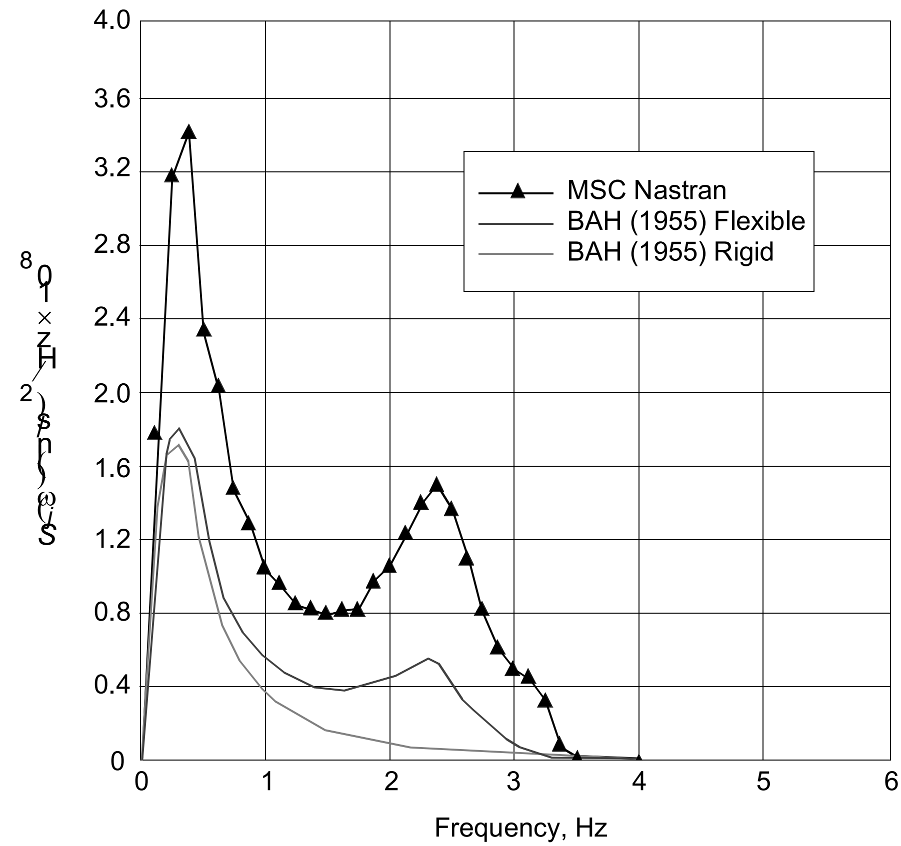
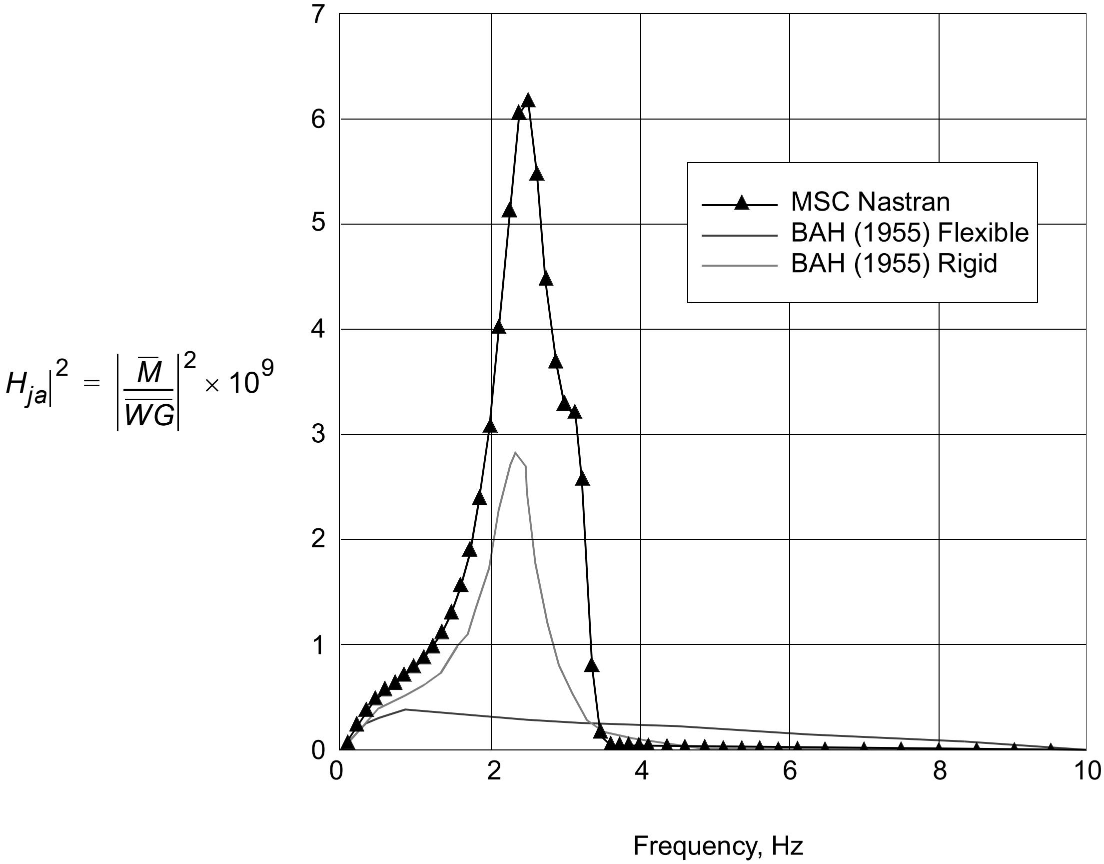


Figure 9-8 Power Spectral Density Function of Wing Root Bending Moment

The earlier solution of Bisplinghoff, Ashley, and Halfman (1955, pp. 693, 694 [Reference 8]) is plotted in Figure 10-26 of that textbook as the frequency response of the mean square root bending moment (called the admittance function in the text), and in Figure 10-27 of that same text as the power spectrum of the root bending moment. These two textbook plots are scaled and added to Figure 9-9 and Figure 9-8, respectively, in this guide for comparisons to the present solution.

Figure 9-9 Frequency Response of Root Bending Moment

The computed results for the two solutions can be compared by calculating $\overline{A}$, the ratio of the root mean square of the response to the input. The textbook solution for the elastic airplane is



$$\bar{A} = \frac{\text{root mean square of bending moment, } \sqrt{\overline{M^2}} \text{ (elastic)}}{\text{root mean square of gust input, } \sqrt{\overline{w_g^2}}} = 16{,}035 \text{ lb-sec} \tag{9-5}$$

while the present solution is $\bar{A} = 20{,}502$ lb-sec. The present solution also obtained the mean frequency $N_0 = 1.620$ Hz. The ratio of N_0 to the airspeed becomes

$$\frac{N_0}{V} = \frac{1.620}{475 \times 88/60} = 0.002325 \frac{\text{crossings/sec}}{\text{ft/s}} \tag{9-6}$$

or, in perhaps more meaningful units, 12.28 crossings per mile of travel.

Listing 9-7 Input Files for Random Gust Response

```
   N A S T R A N    E X E C U T I V E    C O N T R O L    D E C K    E C H O

ID MSC,HA146C
$$$$$$$$          HANDBOOK FOR AEROELASTIC ANALYSIS EXAMPLE                  $$$$$$$$
$                                                                                   $
$       MODEL DESCRIPTION       BAH JET TRANSPORT WING EXAMPLE                      $
$                               USING A STIFF AILERON. SYMMETRIC                    $
$                               RESPONSE TO A RANDOM GUST.                          $
$                                                                                   $
$       SOLUTION                TRANSIENT ANALYSIS USING THE                        $
$                               DOUBLET-LATTICE METHOD AERODYNAMICS                 $
$                               AT MACH NO. OF 0.0                                  $
$                                                                                   $
$       OUTPUT                  XY PLOTS OF MODAL AND GRID POINT                    $
$                               DISPLACEMENTS                                       $
$                                                                                   $
$$$$$$$$                                                                     $$$$$$$$
TIME 10    $ CPU TIME IN MINUTES
SOL 146    $ DYNAMIC AEROELASTIC RESPONSE
CEND


BAH JET TRANSPORT WING DYNAMIC ANALYSIS                HA146C                                                PAGE     2
  SYMMETRIC RESPONSE, 5 STRIPS, DOUBLET-LATTICE AERO

 RESPONSE TO A RANDOM GUST

                                C A S E    C O N T R O L    D E C K    E C H O
             CARD
             COUNT
              1      TITLE = BAH JET TRANSPORT WING DYNAMIC ANALYSIS               HA146C
              2      SUBTI = SYMMETRIC RESPONSE, 5 STRIPS, DOUBLET-LATTICE AERO
              3      LABEL = RESPONSE TO A RANDOM GUST
              4      ECHO = BOTH
              5        SPC    = 14             $ BOUNDARY CONDITIONS (SYMMETRIC, NO PITCH)
              6        METHOD = 10             $ GIVENS EIGENVALUE METHOD
              7        SDAMP  = 2000           $ STRUCTURAL DAMPING (3 PERCENT SPECIFIED)
              8        FREQ   = 40             $ FREQUENCY LIST
              9        RANDOM = 1031           $ EMPIRICAL PSDF TABULATED
             10        K2PP   = STIFF          $ DMIG STIFFNESS
             11      OUTPUT
             12        SET 1 = 50
             13        SET 3 = 11
             14        DISP(PLOT) = 1          $ DISP AND SDISP ARE REQUIRED FOR PSD PLOTS OF         DISP
             15        SDISP(PLOT) = 1
             16        SPCF(PHASE) = 3          $ XY PLOTTING PACKAGE
             17      SUBCASE 1
             18        LABEL =  RANDOM GUST ANALYSIS
             19        GUST  = 3002            $ APPLY THE RANDOM GUST
             20        DLOAD = 3002            $ APPLY LOAD TO EPOINT TO GET PSD OF GUST
             21      OUTPUT(XYOUT)             $ FREQ RESP PACKAGE (COMPLEX NUMBERS)
             22        CSCALE 2.0
             23        PLOTTER = NASTRAN
             24      $
             25      $ *** THIS APPLIES TO SPLIT FRAMES ***
             26      $
             27        TRIGHT TICS = -1
             28        BRIGHT TICS = -1
             29        XTGRID = YES
             30        YTGRID = YES
             31        XBGRID = YES
             32        YBGRID = YES
             33        YTTITLE = MAGNITUDE
             34        YBTITLE = PHASE
```

Listing 9-7 Input Files for Random Gust Response (Continued)

```
$
$ *** THIS SECTION APPLIES TO WHOLE FRAMES ***
$
  UPPER TICS = -1
  RIGHT TICS = -1
  XGRID LINES = YES
  YGRID LINES = YES
  YTITLE = RESPONSE
$
$ *** THIS SECTION APPLIES TO ALL FRAMES ***
$
  XTITLE = FREQUENCY (HZ)
  CURVELINESYMBOL = 6
$
$ *** FREQUENCY RESPONSE PLOT REQUESTS ***
$
  TCURVE = WING ROOT BENDING MOMENT, GRID 11(R3)
    XYPLOT  SPCF / 11(R3RM,R3IP)
$
$ *** RANDOM ANALYSIS OUTPUT REQUESTS ***
$
  TCURVE = POWER SPECTRAL DENSITY FUNCTION
    YTITLE = WING ROOT BENDING MOMENT PSD, 11(R3)
    XYPRINT,XYPLOT  SPCF  PSDF  / 11(R3)
$
  TCURVE = POWER SPECTRAL DENSITY FUNCTION
  YTITLE = GUST PSD USING EPOINT 50 FOR OUTPUT
  XYPRINT,XYPLOT SDISP PSDF / 50(T1)
  XYPRINT,XYPLOT  DISP PSDF / 50(T1)
$
BEGIN BULK
```

```
BAH JET TRANSPORT WING DYNAMIC ANALYSIS                HA146C                                                          PAGE    4
  SYMMETRIC RESPONSE, 5 STRIPS, DOUBLET-LATTICE AERO
 RESPONSE TO A RANDOM GUST
                I N P U T  B U L K  D A T A  D E C K  E C H O
                        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                        INCLUDE BAH_STRUCT.DAT
                        $
                        INCLUDE BAH_MASS.DAT
                        $
                        $        TABDMP1 DEFINES DAMPING COEFFICIENTS (G1) VERSES FREQUENCY (F1).
                        $        (3 PERCENT STRUCTURAL DAMPING IS SPECIFIED OVER THE ENTIRE FREQUENCY
                        $        RANGE. VALUES ARE LINEARLY INTERPOLATED AND EXTRAPOLATED. A 3%
                        $        STRUCTURAL DAMPING IS ROUGHLY EQUIVALENT TO 1.5% CRITICAL DAMPING.)
                        $
                        $       ID      TYPE
                        TABDMP1 2000                                                            +TABDMP
                        +TABDMP 0.      .03     10.     .03     ENDT
                        $
                        $                        * * CONSTRAINTS * *
                        $
                        $        THE SPC ENTRY CONSTRAINS DOFS.
                        $
                        $       SID     G       C       D
                        SPC     14      11      45
                        $
                        $* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                        $
                        $                  * * DYNAMIC LOAD AND RESPONSE DATA * *
                        $
                        $        GUST DEFINES A STATIONARY VERTICAL GUST.  LISTED ARE T/RLOAD ENTRY
                        $        ID, RATIO OF GUST VEL/VEHICLE VEL, LOCATION OF THE GUST WITH RESPECT
                        $        TO THE ORIGIN OF THE AERO COORDINATE SYSTEM AND VEHICLE VELOCITY.
                        $
                        $       SID     DLOAD   WG      X0      V
                        GUST    3002    3002    1.1962-4 0.     8360.
                        $
                        $        RLOAD1 DEFINES A FREQUENCY DEPENDENT DYNAMIC LOAD.  LISTED ARE
                        $        THE ID, DAREA ID, DELAY ID, DPHASE ID AND TABLEDI ENTRIES
                        $
                        $       SID     L       M       N       TC      TD
                        RLOAD1  3002    3003                    3004
                        $
                        $        DAREA DEFINES THE DOF WHERE THE LOAD IS APPLIED AND A SCALE FACTOR.
```

Listing 9-7 Input Files for Random Gust Response (Continued)

```
$
$       SID     P       C       A
DAREA   3003    50              1.
$
$        TABLED1 DEFINES A TABULAR FUNCTION OF A FREQUENCY-DEPENDENT LOAD.
$
$       SID
TABLED1 3004                                                            +T1004
$       X1      Y1      X2      Y2      ETC.
+T1004  0.      1.      10.     1.      ENDT
$
$        RANDPS DEFINES POWER SPECTRAL DENISITY FACTORS FOR RANDOM
$        ANALYSIS. LISTED ARE EXCITED AND APPLIED LOAD SET IDS AND
$        THEIR SCALE FACTORS.
$
$       SID     J       K       X       Y       TID
RANDPS  1031    1       1       1.0     0.0     1032
$
$        TABRND1 IS THE POWER SPECTRAL DENSITY TABLE.
$
TABRND1 1032                                                          +001
+001     0.00   2.8708+0 0.25   1.2641+0 0.50   4.7188-1 0.75   2.3080-1+002
+002     1.00   1.3456-1 1.25   8.7595-2 1.50   6.1402-2 1.75   4.5369-2+003
+003     2.00   3.4865-2 2.25   2.7618-2 2.50   2.2412-2 2.75   1.8547-2+004
+004     3.00   1.5601-2 3.25   1.3304-2 3.50   1.1478-2 3.75   1.0004-2+005
+005     4.00   8.7964-3 4.25   7.7947-3 4.50   6.9547-3 4.75   6.2434-3+006
+006     5.00   5.6359-3 5.25   5.1128-3 5.50   4.6593-3 5.75   4.2636-3+007
+007     6.00   3.9162-3 6.25   3.6095-3 6.50   3.3375-3 6.75   3.0951-3+008
+008     7.00   2.8782-3 7.25   2.6833-3 7.50   2.5076-3 7.75   2.3485-3+009
+009     8.00   2.2042-3 8.25   2.0727-3 8.50   1.9526-3 8.75   1.8427-3+010
+010     9.00   1.7418-3 9.25   1.6490-3 9.50   1.5634-3 9.75   1.4843-3+011
+011     10.00  1.4440-3 ENDT
$
$* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
$
$                      * * * AERODYNAMIC DATA * * *
$
$                (THIS MODEL USES THE LB-IN-SEC SYSTEM)
$
$                        * * ELEMENT GEOMETRY * *
$
$        THE AERO ENTRY DEFINES BASIC AERODYNAMIC PARAMETERS. ACSID IS THE
$        AERO COORDINATE SYSTEM. VELOCITY. REFC IS THE REFERENECE
$        COORDINATE SYSTEM. RHOREF IS REFERENCE DENSITY. SYMXZ AND
$        SYMXY ARE SYMMETRY KEYS.
$
$       ACSID   VELOCITY REFC   RHOREF  SYMXZ   SYMXY
AERO    1       8360.   131.232 1.1468-71
$
INCLUDE BAH_AERO5.DAT
$
$        THE MKAERO1 ENTRY DEFINES COMBINATIONS OF MACH NUMBER AND REDUCED
$        FREQUENCY EACH OF WHICH WILL BE USED TO GENERATE A MATRIX OF
$        GENERALIZED AERODYNAMIC FORCES.
$
$       M1      M2      M3      M4      ETC
MKAERO1 .62                                                           +MK
$       K1      K2      K3      K4      ETC
+MK     0.001   0.02    0.10    0.50
$
$       PARAM,GUSTAERO,-1 IS REQUIRED IF GUST LOADS ARE TO BE COMPUTED.
$
PARAM   GUSTAERO -1
$
$       PARAM,M SPECIFIES MACH NUMBER.
$
PARAM   M       0.62
$
$       PARAM,Q SPECIFIES DYNAMIC PRESSURE.
$
PARAM   Q       4.00747
$
$* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

Listing 9-7 Input Files for Random Gust Response (Continued)

```
$
$               * * VIBRATION AND FREQUENCY RESPONSE DATA * *
$
$        EIGR DEFINES EIGENVALUE EXTRACTION DATA.  LISTED ARE THE
$        EIGENVALUE EXTRACTION METHOD, FREQUENCY RANGE, NUMBER OF
$        EXPECTED AND DESIRED ROOTS AND THE METHOD OF NORMALIZATION.
$
$       SID     METHOD  F1      F2      NE      ND
EIGR    10      GIV     0.      1.              11                      +EIGR
+EIGR   MAX
$
$        FREQ AND FREQ1 DEFINE THE SET OF FREQUENCIES USED TO OBTAIN
$        THE FREQUENCY RESPONSE SOLUTION.  FREQ LISTS ARBITRARILY
$        SPACED FREQUENCIES.  FREQ1 PROVIDES EQUALLY SPACED FREQUENCIES
$        BY SPECIFYING THE STARTING FREQUENCY, THE FREQUENCY INCREMENT
$        AND NUMBER OF INCREMENTS.
$
$       SID     F1      F2      F3      ETC
FREQ    40      0.001
$
$       SID     F1      DF      NDF
FREQ1   40      .125    .125    79
$
$* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
$
$       THE EPOINT ENTRY DEFINES AN "EXTRA" POINT IN THE MODEL.
$
EPOINT  50
$
$        DISJOINT DOF ADDED TO THE STRUCTURAL STIFFNESS MATRIX
$        WHICH IS USED TO CHECK THE INPUT GUST PSD.
$
$       NAME    "0"     IFO     TIN     TOUT    POLAR           NCOL
DMIG    STIFF   0       6       1       0
DMIG    STIFF   50      0               50      0       1.
$
$* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
ENDDATA
INPUT BULK DATA CARD COUNT =     360
```

Listing 9-8 Sorted Bulk Data Entries for Random Gust Response

```
BAH JET TRANSPORT WING DYNAMIC ANALYSIS                HA146C                                                   PAGE  12
 SYMMETRIC RESPONSE, 5 STRIPS, DOUBLET-LATTICE AERO
 RESPONSE TO A RANDOM GUST
                                            S O R T E D   B U L K   D A T A   E C H O
           CARD
           COUNT        .  1  ..  2  ..  3  ..  4  ..  5  ..  6  ..  7  ..  8  ..  9  ..  10  .
              1-        AEFACT  77      .0      .09     .276    .454    .636    .826    1.0
              2-        AERO    1       8360.   131.232 1.1468-71
              3-        CAERO1  1001    1000    0               4       77              1       +CA1
              4-        +CA1    78.75   0.0     0.0     225.0   35.0    500.0   0.0     100.0
              5-        CMASS2  121     5248.7  1       3
              6-        CMASS2  122     134.9   1       3       2       3
              7-        CMASS2  123     790.3   2       3
              8-        CMASS2  341     9727.   3       3
              9-        CMASS2  342     11005.  3       3       4       3
             10-        CMASS2  343     473.    4       3
             11-        CMASS2  561     3253.6  5       3
             12-        CMASS2  562     -139.7  5       3       6       3
             13-        CMASS2  563     946.3   6       3
             14-        CMASS2  781     2617.8  7       3
             15-        CMASS2  782     21.     7       3       8       3
             16-        CMASS2  783     782.3   8       3
             17-        CMASS2  9101    494.8   9       3
             18-        CMASS2  9102    -7.3    9       3       10      3
             19-        CMASS2  9103    185.2   10      3
             20-        CONM1   1       11                                                      +51
             21-        +51     17400.                          4.37+7                          +52
             22-        +52             4.35+09
             23-        CORD2R  1               0.      0.      0.      0.      0.      -1.     +C1
             24-        +C1     -1.     0.      0.
             25-        DAREA   3003    50              1.
             26-        DMIG    STIFF   0       6       1       0
             27-        DMIG    STIFF   50      0               50      0       1.
             28-        EIGR    10      GIV     0.      1.              11                      +EIGR
             29-        +EIGR   MAX
             30-        EPOINT  50
             31-        FREQ    40      0.001
             32-        FREQ1   40      .125    .125    79
             33-        GENEL   432             1       3       2       3       3       3       +01
             34-        +01     4       3       5       3       6       3       7       3       +02
             35-        +02     8       3       9       3       10      3                       +03
             36-        +03     UD              11      3       11      4       11      5       +04
             37-        +04     11      6                                                       +05
             38-        +05     Z       8.7172-61.3361-61.2778-56.2720-61.6251-51.0492-52.0478-5+06
             39-        +06     1.5630-52.4285-52.0403-53.0861-56.2720-63.2297-51.0492-53.3529-5+07
             40-        +07     1.5630-53.5021-52.0257-53.5785-52.7732-51.5726-54.8255-53.7628-5+08
             41-        +08     7.3284-56.4338-59.5810-58.8378-56.3749-53.7628-58.0136-56.4338-5+09
             42-        +09     1.0012-48.8378-51.1811-41.2758-41.1344-41.9350-41.8160-42.5283-4+10
             43-        +10     2.4294-41.6999-41.8160-42.2920-42.4294-42.8249-43.6862-43.5052-4+11
             44-        +11     5.2675-45.1171-44.2292-45.1171-45.7187-48.4840-48.2340-49.2340-4+12
             45-        +12     S       1.0     90.0    -20.25  45.0    1.0     90.0    81.0    +13
             46-        +13     45.0    1.0     186.0   -17.85  141.0   1.0     186.0   71.4    +14
             47-        +14     141.0   1.0     268.0   -15.80  223.0   1.0     268.0   63.2    +15
             48-        +15     223.0   1.0     368.0   -13.30  323.0   1.0     368.0   53.2    +16
             49-        +16     323.0   1.0     458.0   -11.05  413.0   1.0     458.0   44.2    +17
             50-        +17     413.0
             51-        GRID    1               20.25   90.                     12456
             52-        GRID    2               -81.    90.                     12456
             53-        GRID    3               17.85   186.                    12456
             54-        GRID    4               -71.4   186.                    12456
             55-        GRID    5               15.8    268.                    12456
             56-        GRID    6               -63.2   268.                    12456
             57-        GRID    7               13.3    368.                    12456
             58-        GRID    8               -53.2   368.                    12456
             59-        GRID    9               11.05   458.                    12456
             60-        GRID    10              -44.2   458.                    12456
             61-        GRID    11              0.0     0.                      126
             62-        GUST    3002    3002    1.1962-40.      8360.
             63-        MKAERO1 .62                                                             +MK
             64-        +MK     0.001   0.02    0.10    0.50
             65-        PAERO1  1000
             66-        PARAM   GRDPNT  11
             67-        PARAM   GUSTAERO-1
             68-        PARAM   M       0.62
             69-        PARAM   Q       4.00747
             70-        PARAM   WTMASS  .0025907
```

Listing 9-8 Sorted Bulk Data Entries for Random Gust Response (Continued)

```
 71-        RANDPS  1031    1       1       1.0     0.0     1032
 72-        RLOAD1  3002    3003                    3004
 73-        SET1    14      1       THRU    11
 74-        SPC     14      11      45
 75-        SPLINE2 100     1001    1005    1024    14      0.0     1.0     0       +SP100
 76-        +SP100  -1.0    -1.0
 77-        TABDMP1 2000                                                            +TABDMP
 78-        +TABDMP 0.      .03     10.     .03     ENDT
 79-        TABLED1 3004                                                            +T1004
 80-        +T1004  0.      1.      10.     1.      ENDT
 81-        TABRND1 1032                                                            +001
 82-        +001    0.00    2.8708+00.25    1.2641+00.50    4.7188-10.75    2.3080-1+002
 83-        +002    1.00    1.3456-11.25    8.7595-21.50    6.1402-21.75    4.5369-2+003
 84-        +003    2.00    3.4865-22.25    2.7618-22.50    2.2412-22.75    1.8547-2+004
 85-        +004    3.00    1.5601-23.25    1.3304-23.50    1.1478-23.75    1.0004-2+005
 86-        +005    4.00    8.7964-34.25    7.7947-34.50    6.9547-34.75    6.2434-3+006
 87-        +006    5.00    5.6359-35.25    5.1128-35.50    4.6593-35.75    4.2636-3+007
 88-        +007    6.00    3.9162-36.25    3.6095-36.50    3.3375-36.75    3.0951-3+008
 89-        +008    7.00    2.8782-37.25    2.6833-37.50    2.5076-37.75    2.3485-3+009
 90-        +009    8.00    2.2042-38.25    2.0727-38.50    1.9526-38.75    1.8427-3+010
 91-        +010    9.00    1.7418-39.25    1.6490-39.50    1.5634-39.75    1.4843-3+011
 92-        +011    10.00   1.4440-3ENDT
            ENDDATA
      TOTAL COUNT=        93
```

Listing 9-9 Output for Random Gust Response

```
BAH JET TRANSPORT WING DYNAMIC ANALYSIS                HA146C                                                     PAGE  18
 SYMMETRIC RESPONSE, 5 STRIPS, DOUBLET-LATTICE AERO
 RESPONSE TO A RANDOM GUST
                                            R E A L   E I G E N V A L U E S
MODE    EXTRACTION      EIGENVALUE           RADIANS             CYCLES              GENERALIZED         GENERALIZED
 NO.       ORDER                                                                        MASS              STIFFNESS
     1         8        1.275478E-12        1.129371E-06        1.797449E-07        1.085996E+02        1.385164E-10
     2         9        2.344038E+02        1.531025E+01        2.436702E+00        7.333811E+00        1.719073E+03
     3        10        5.021460E+02        2.240862E+01        3.566442E+00        4.860579E+01        2.440721E+04
     4         7        2.873470E+03        5.360476E+01        8.531462E+00        6.036275E+00        1.734505E+04
     5         6        6.346819E+03        7.966693E+01        1.267939E+01        1.389629E+01        8.819726E+04
     6        11        8.746056E+03        9.352035E+01        1.488422E+01        3.997501E+00        3.496237E+04
     7         5        1.766041E+04        1.328925E+02        2.115050E+01        3.884947E+00        6.860977E+04
     8         4        2.401137E+04        1.549560E+02        2.466202E+01        3.570773E+00        8.573913E+04
     9         3        4.211877E+04        2.052286E+02        3.266314E+01        3.142323E+00        1.323508E+05
    10         2        6.020940E+04        2.453760E+02        3.905281E+01        1.016273E+00        6.118916E+04
    11         1        9.492829E+04        3.081043E+02        4.903633E+01        8.935863E+00        8.482661E+05
```

Listing 9-9 Output for Random Gust Response (Continued)

```
                              X Y - O U T P U T  S U M M A R Y  ( A U T O  O R  P S D F )
 PLOT  CURVE FRAME                     RMS         NO. POSITIVE   XMIN FOR   XMAX FOR   YMIN FOR    X FOR      YMAX FOR    X FOR*
TYPE   TYPE   NO.    CURVE ID.        VALUE         CROSSINGS    ALL DATA   ALL DATA   ALL DATA     YMIN      ALL DATA     YMAX
 PSDF DISP      1        50(  3)   9.953058E-01  1.177425E+00  1.000E-03  1.000E+01  1.444E-03  1.000E+01  2.864E+00  1.000E-03

                          P R I N T E D   D A T A   F O R   T H I S   C U R V E   F O L L O W S
     DISPLACEMENT    CURVE   ID =       50     COMPONENT =  3     WHOLE FRAME
                             PRINT NUMBER          X-VALUE              Y-VALUE
                                  1             1.000000E-03         2.864373E+00
                                  2             1.250000E-01         2.067450E+00
                                  3             2.500000E-01         1.264100E+00
                                  4             3.750000E-01         8.679900E-01
                                  5             5.000000E-01         4.718800E-01
                                  6             6.250000E-01         3.513400E-01
                                  7             7.500000E-01         2.308000E-01
                                  8             8.749999E-01         1.826800E-01
                                  9             1.000000E+00         1.345600E-01
                                 10             1.125000E+00         1.110775E-01
                                 11             1.250000E+00         8.759500E-02
                                 12             1.375000E+00         7.449849E-02
                                 13             1.500000E+00         6.140199E-02
                                 14             1.625000E+00         5.338550E-02
                                 15             1.750000E+00         4.536900E-02
                                 16             1.875000E+00         4.011700E-02
                                 17             2.000000E+00         3.486500E-02
                                 18             2.125000E+00         3.124150E-02
                                 19             2.250000E+00         2.761800E-02
                                 20             2.375000E+00         2.501500E-02
                                 21             2.500000E+00         2.241200E-02
                                 22             2.625000E+00         2.047950E-02
                                 23             2.750000E+00         1.854700E-02
                                 24             2.875000E+00         1.707400E-02
                                 25             3.000000E+00         1.560100E-02
                                 26             3.125000E+00         1.445250E-02
                                 27             3.250000E+00         1.330400E-02
                                 28             3.375000E+00         1.239100E-02
                                 29             3.500000E+00         1.147800E-02
                                 30             3.625000E+00         1.074100E-02
                                 31             3.750000E+00         1.000400E-02
                                 32             3.875000E+00         9.400200E-03
                                 33             4.000000E+00         8.796400E-03
                                 34             4.125000E+00         8.295550E-03
                                 35             4.250000E+00         7.794700E-03
                                 36             4.375000E+00         7.374700E-03
                                 37             4.500000E+00         6.954700E-03
                                 38             4.625000E+00         6.599050E-03
                                 39             4.750000E+00         6.243400E-03
                                 40             4.875000E+00         5.939650E-03
                                 41             5.000000E+00         5.635900E-03
                                 42             5.125000E+00         5.374350E-03
                                 43             5.250000E+00         5.112801E-03
                                 44             5.375000E+00         4.886050E-03
                                 45             5.500000E+00         4.659301E-03
                                 46             5.625000E+00         4.461450E-03
                                 47             5.750000E+00         4.263601E-03
                                 48             5.875000E+00         4.089901E-03
                                 49             6.000000E+00         3.916200E-03
                                 50             6.125000E+00         3.762851E-03
                                 51             6.250000E+00         3.609500E-03
                                 52             6.375000E+00         3.473500E-03
                                 53             6.500000E+00         3.337500E-03
                                 54             6.625000E+00         3.216300E-03
                                 55             6.750000E+00         3.095100E-03
                                 56             6.875000E+00         2.986650E-03
                                 57             7.000000E+00         2.878200E-03
                                 58             7.125000E+00         2.780750E-03
                                 59             7.250000E+00         2.683301E-03
                                 60             7.375000E+00         2.595450E-03
                                 61             7.500000E+00         2.507600E-03
                                 62             7.625000E+00         2.428050E-03
                                 63             7.750000E+00         2.348500E-03
                                 64             7.875000E+00         2.276350E-03
                                 65             8.000000E+00         2.204200E-03
                                 66             8.125000E+00         2.138450E-03
                                 67             8.249999E+00         2.072701E-03
                                 68             8.375000E+00         2.012650E-03
                                 69             8.500000E+00         1.952600E-03
                                 70             8.625000E+00         1.897650E-03
                                 71             8.750000E+00         1.842700E-03
                                 72             8.875000E+00         1.792250E-03
                                 73             9.000000E+00         1.741800E-03
                                 74             9.124999E+00         1.695400E-03
                                 75             9.250000E+00         1.649000E-03
                                 76             9.375000E+00         1.606200E-03
                                 77             9.500000E+00         1.563400E-03
                                 78             9.625000E+00         1.523850E-03
                                 79             9.749999E+00         1.484300E-03
                                 80             9.875000E+00         1.464150E-03
                                 81             1.000000E+01         1.444000E-03
```

Listing 9-9 Output for Random Gust Response (Continued)

```
     POINT-ID =        11
                                 C O M P L E X   F O R C E S   O F   S I N G L E   P O I N T   C O N S T R A I N T
                                                                (MAGNITUDE/PHASE)

     FREQUENCY    TYPE          T1              T2              T3              R1              R2              R3
  1.000000E-03     G      0.0             0.0             0.0             8.312178E+02    3.395612E+01    8.308215E+02
                          0.0             0.0             0.0           173.6820        359.8732        174.6252
  1.250000E-01     G      0.0             0.0             0.0             1.092055E+04    1.230243E+03    9.330418E+03
                          0.0             0.0             0.0            71.1811        248.5424         71.8331
  2.500000E-01     G      0.0             0.0             0.0             1.861192E+04    2.087676E+03    1.589639E+04
                          0.0             0.0             0.0            50.7622        229.3616         51.0190
  3.750000E-01     G      0.0             0.0             0.0             2.326442E+04    2.585104E+03    1.987951E+04
                          0.0             0.0             0.0            36.7060        215.6992         36.7986
  5.000000E-01     G      0.0             0.0             0.0             2.614285E+04    2.865934E+03    2.235717E+04
                          0.0             0.0             0.0            26.6160        205.8111         26.6021
  6.250000E-01     G      0.0             0.0             0.0             2.814698E+04    3.031500E+03    2.409714E+04
                          0.0             0.0             0.0            18.9874        198.3330         18.8895
  7.500000E-01     G      0.0             0.0             0.0             2.976732E+04    3.135313E+03    2.551859E+04
                          0.0             0.0             0.0            12.8939        192.3960         12.7225
  8.749999E-01     G      0.0             0.0             0.0             3.127258E+04    3.204327E+03    2.685191E+04
                          0.0             0.0             0.0             7.7702        187.4722          7.5306
  1.000000E+00     G      0.0             0.0             0.0             3.282730E+04    3.252165E+03    2.823920E+04
                          0.0             0.0             0.0             3.2554        183.2352          2.9501
  1.125000E+00     G      0.0             0.0             0.0             3.455186E+04    3.285456E+03    2.978557E+04
                          0.0             0.0             0.0           359.0998        179.4765        358.7296
  1.250000E+00     G      0.0             0.0             0.0             3.655425E+04    3.306606E+03    3.158650E+04
                          0.0             0.0             0.0           355.1104        176.0588        354.6748
  1.375000E+00     G      0.0             0.0             0.0             3.894966E+04    3.314806E+03    3.374499E+04
                          0.0             0.0             0.0           351.1161        172.8939        350.6140
  1.500000E+00     G      0.0             0.0             0.0             4.187598E+04    3.305959E+03    3.638537E+04
                          0.0             0.0             0.0           346.9409        169.9370        346.3704
  1.625000E+00     G      0.0             0.0             0.0             4.550782E+04    3.271766E+03    3.966609E+04
                          0.0             0.0             0.0           342.3771        167.2026        341.7360
  1.750000E+00     G      0.0             0.0             0.0             5.006727E+04    3.198116E+03    4.379009E+04
                          0.0             0.0             0.0           337.1540        164.8229        336.4393
  1.875000E+00     G      0.0             0.0             0.0             5.581818E+04    3.063984E+03    4.900098E+04
                          0.0             0.0             0.0           330.8942        163.2185        330.1027
  2.000000E+00     G      0.0             0.0             0.0             6.299762E+04    2.847984E+03    5.552409E+04
                          0.0             0.0             0.0           323.0629        163.5802        322.1909
  2.125000E+00     G      0.0             0.0             0.0             7.155795E+04    2.576946E+03    6.333834E+04
                          0.0             0.0             0.0           312.9433        169.0459        311.9869
  2.250000E+00     G      0.0             0.0             0.0             8.049985E+04    2.521016E+03    7.157834E+04
                          0.0             0.0             0.0           299.7882        184.3782        298.7429
  2.375000E+00     G      0.0             0.0             0.0             8.702245E+04    3.313615E+03    7.775445E+04
                          0.0             0.0             0.0           283.4468        201.3680        282.3080
  2.500000E+00     G      0.0             0.0             0.0             8.756493E+04    5.049220E+03    7.864403E+04
                          0.0             0.0             0.0           265.3443        204.1534        264.1071
  2.625000E+00     G      0.0             0.0             0.0             8.187171E+04    7.199502E+03    7.393528E+04
                          0.0             0.0             0.0           248.1337        197.1053        246.7932
  2.750000E+00     G      0.0             0.0             0.0             7.365701E+04    9.551510E+03    6.690588E+04
                          0.0             0.0             0.0           233.4971        187.0322        232.0486
  2.875000E+00     G      0.0             0.0             0.0             6.653845E+04    1.242790E+04    6.081651E+04
                          0.0             0.0             0.0           221.0725        175.9375        219.5118
  3.000000E+00     G      0.0             0.0             0.0             6.234854E+04    1.664170E+04    5.736808E+04
                          0.0             0.0             0.0           208.7704        162.5133        207.0944
  3.125000E+00     G      0.0             0.0             0.0             6.116080E+04    2.349440E+04    5.668552E+04
                          0.0             0.0             0.0           191.8247        141.8488        190.0315
  3.250000E+00     G      0.0             0.0             0.0             5.440966E+04    3.066718E+04    5.084297E+04
                          0.0             0.0             0.0           161.7768        104.3605        159.8614
  3.375000E+00     G      0.0             0.0             0.0             3.006864E+04    2.526187E+04    2.837297E+04
                          0.0             0.0             0.0           132.3735         61.0607        130.3016
  3.500000E+00     G      0.0             0.0             0.0             1.407659E+04    1.658689E+04    1.343349E+04
                          0.0             0.0             0.0           132.2889         36.5247        129.9028
  3.625000E+00     G      0.0             0.0             0.0             8.872051E+03    1.142868E+04    8.537994E+03
                          0.0             0.0             0.0           151.2876         23.9947        148.3866
  3.750000E+00     G      0.0             0.0             0.0             7.594335E+03    8.424339E+03    7.345599E+03
                          0.0             0.0             0.0           168.1369         16.6051        164.8525
  3.875000E+00     G      0.0             0.0             0.0             7.170586E+03    6.527583E+03    6.978353E+03
                          0.0             0.0             0.0           177.4938         11.6843        173.9513
  4.000000E+00     G      0.0             0.0             0.0             6.835414E+03    5.241428E+03    6.702518E+03
                          0.0             0.0             0.0           182.4707          8.1275        178.6795
  4.125000E+00     G      0.0             0.0             0.0             6.472588E+03    4.320244E+03    6.400520E+03
                          0.0             0.0             0.0           185.3352          5.4098        181.2695
  4.250000E+00     G      0.0             0.0             0.0             6.087274E+03    3.632354E+03    6.074047E+03
                          0.0             0.0             0.0           187.1697          3.2509        182.7957
  4.375000E+00     G      0.0             0.0             0.0             5.697985E+03    3.101771E+03    5.739547E+03
                          0.0             0.0             0.0           188.4894          1.4870        183.7707
  4.500000E+00     G      0.0             0.0             0.0             5.318625E+03    2.681875E+03    5.409977E+03
                          0.0             0.0             0.0           189.5563          0.0153        184.4546
  4.625000E+00     G      0.0             0.0             0.0             4.957508E+03    2.342602E+03    5.093353E+03
                          0.0             0.0             0.0           190.5126        358.7673        184.9872
  4.750000E+00     G      0.0             0.0             0.0             4.618969E+03    2.063747E+03    4.794036E+03
                          0.0             0.0             0.0           191.4413        357.6955        185.4486
  4.875000E+00     G      0.0             0.0             0.0             4.304840E+03    1.831257E+03    4.514035E+03
                          0.0             0.0             0.0           192.3934        356.7653        185.8867
```

Listing 9-9 Output for Random Gust Response (Continued)

```
     5.000000E+00     G      0.0            0.0            0.0             4.015488E+03   1.635066E+03   4.253931E+03
                             0.0            0.0            0.0            193.4026       355.9508       186.3322
     5.125000E+00     G      0.0            0.0            0.0             3.750462E+03   1.467788E+03   4.013496E+03
                             0.0            0.0            0.0            194.4919       355.2320       186.8046
     5.250000E+00     G      0.0            0.0            0.0             3.508895E+03   1.323882E+03   3.792052E+03
                             0.0            0.0            0.0            195.6777       354.5926       187.3176
     5.375000E+00     G      0.0            0.0            0.0             3.289765E+03   1.199116E+03   3.588719E+03
                             0.0            0.0            0.0            196.9724       354.0196       187.8814
     5.500000E+00     G      0.0            0.0            0.0             3.092037E+03   1.090203E+03   3.402559E+03
                             0.0            0.0            0.0            198.3841       353.5018       188.5032
     5.625000E+00     G      0.0            0.0            0.0             2.914741E+03   9.945497E+02   3.232650E+03
                             0.0            0.0            0.0            199.9180       353.0295       189.1890
     5.750000E+00     G      0.0            0.0            0.0             2.757052E+03   9.100891E+02   3.078166E+03
                             0.0            0.0            0.0            201.5756       352.5945       189.9436
     5.875000E+00     G      0.0            0.0            0.0             2.618288E+03   8.351497E+02   2.938391E+03
                             0.0            0.0            0.0            203.3531       352.1884       190.7699
     6.000000E+00     G      0.0            0.0            0.0             2.497961E+03   7.683656E+02   2.812764E+03
                             0.0            0.0            0.0            205.2426       351.8042       191.6710
     6.125000E+00     G      0.0            0.0            0.0             2.395750E+03   7.086125E+02   2.700880E+03
                             0.0            0.0            0.0            207.2279       351.4343       192.6471
     6.250000E+00     G      0.0            0.0            0.0             2.311544E+03   6.549512E+02   2.602533E+03
                             0.0            0.0            0.0            209.2858       351.0716       193.6978
     6.375000E+00     G      0.0            0.0            0.0             2.245442E+03   6.065951E+02   2.517735E+03
                             0.0            0.0            0.0            211.3835       350.7089       194.8195
     6.500000E+00     G      0.0            0.0            0.0             2.197763E+03   5.628750E+02   2.446741E+03
                             0.0            0.0            0.0            213.4780       350.3384       196.0057
     6.625000E+00     G      0.0            0.0            0.0             2.169088E+03   5.232190E+02   2.390105E+03
                             0.0            0.0            0.0            215.5149       349.9518       197.2444
     6.750000E+00     G      0.0            0.0            0.0             2.160351E+03   4.871305E+02   2.348757E+03
                             0.0            0.0            0.0            217.4304       349.5409       198.5189
     6.875000E+00     G      0.0            0.0            0.0             2.172853E+03   4.541738E+02   2.324048E+03
                             0.0            0.0            0.0            219.1474       349.0944       199.8016
     7.000000E+00     G      0.0            0.0            0.0             2.208555E+03   4.239588E+02   2.317954E+03
                             0.0            0.0            0.0            220.5804       348.6017       201.0558
     7.125000E+00     G      0.0            0.0            0.0             2.270234E+03   3.961263E+02   2.333218E+03
                             0.0            0.0            0.0            221.6316       348.0492       202.2285
     7.250000E+00     G      0.0            0.0            0.0             2.361873E+03   3.703334E+02   2.373637E+03
                             0.0            0.0            0.0            222.1888       347.4201       203.2455
     7.375000E+00     G      0.0            0.0            0.0             2.489371E+03   3.462328E+02   2.444575E+03
                             0.0            0.0            0.0            222.1230       346.6966       204.0064
     7.500000E+00     G      0.0            0.0            0.0             2.661321E+03   3.234458E+02   2.553544E+03
                             0.0            0.0            0.0            221.2744       345.8563       204.3697
     7.625000E+00     G      0.0            0.0            0.0             2.890586E+03   3.015194E+02   2.711320E+03
                             0.0            0.0            0.0            219.4369       344.8768       204.1369
     7.750000E+00     G      0.0            0.0            0.0             3.195997E+03   2.798513E+02   2.933142E+03
                             0.0            0.0            0.0            216.3201       343.7400       203.0152
     7.875000E+00     G      0.0            0.0            0.0             3.605222E+03   2.575742E+02   3.240458E+03
                             0.0            0.0            0.0            211.4979       342.4680       200.5678
     8.000000E+00     G      0.0            0.0            0.0             4.154430E+03   2.334054E+02   3.659708E+03
                             0.0            0.0            0.0            204.3017       341.2171       196.1075
     8.125000E+00     G      0.0            0.0            0.0             4.874108E+03   2.057729E+02   4.208632E+03
                             0.0            0.0            0.0            193.6824       340.6236       188.5583
     8.249999E+00     G      0.0            0.0            0.0             5.720918E+03   1.749926E+02   4.837537E+03
                             0.0            0.0            0.0            178.2120       342.8162       176.4560
     8.375000E+00     G      0.0            0.0            0.0             6.403101E+03   1.522189E+02   5.290097E+03
                             0.0            0.0            0.0            156.9885       351.7622       158.8477
     8.500000E+00     G      0.0            0.0            0.0             6.401133E+03   1.580326E+02   5.146721E+03
                             0.0            0.0            0.0            132.2299         3.0602       137.8788
     8.625000E+00     G      0.0            0.0            0.0             5.689188E+03   1.791391E+02   4.426384E+03
                             0.0            0.0            0.0            109.1909         5.9914       118.7027
     8.750000E+00     G      0.0            0.0            0.0             4.799419E+03   1.928594E+02   3.587265E+03
                             0.0            0.0            0.0             90.7374         3.7587       104.0497
     8.875000E+00     G      0.0            0.0            0.0             4.061349E+03   1.976025E+02   2.892257E+03
                             0.0            0.0            0.0             76.3440         0.5925        93.2252
     9.000000E+00     G      0.0            0.0            0.0             3.525807E+03   1.973737E+02   2.372418E+03
                             0.0            0.0            0.0             64.7253       357.6738        84.7535
     9.124999E+00     G      0.0            0.0            0.0             3.156222E+03   1.949030E+02   1.992135E+03
                             0.0            0.0            0.0             54.9671       355.1408        77.5275
     9.250000E+00     G      0.0            0.0            0.0             2.909021E+03   1.915779E+02   1.713875E+03
                             0.0            0.0            0.0             46.5406       352.9121        70.8558
     9.375000E+00     G      0.0            0.0            0.0             2.750960E+03   1.880790E+02   1.510536E+03
                             0.0            0.0            0.0             39.1600       350.8983        64.3460
     9.500000E+00     G      0.0            0.0            0.0             2.658426E+03   1.847394E+02   1.363717E+03
                             0.0            0.0            0.0             32.6488       349.0218        57.7964
     9.625000E+00     G      0.0            0.0            0.0             2.615604E+03   1.817386E+02   1.261552E+03
                             0.0            0.0            0.0             26.9021       347.2419        51.1629
     9.749999E+00     G      0.0            0.0            0.0             2.611242E+03   1.791593E+02   1.195620E+03
                             0.0            0.0            0.0             21.8159       345.5139        44.4862
     9.875000E+00     G      0.0            0.0            0.0             2.637926E+03   1.770507E+02   1.160150E+03
                             0.0            0.0            0.0             17.3079       343.8145        37.8807
     1.000000E+01     G      0.0            0.0            0.0             2.690929E+03   1.754470E+02   1.151029E+03
                             0.0            0.0            0.0             13.3131       342.1386        31.4983
```

Listing 9-9 Output for Random Gust Response (Continued)

```
                          X Y - O U T P U T   S U M M A R Y   ( A U T O   O R   P S D F )
 PLOT  CURVE FRAME                      RMS        NO. POSITIVE   XMIN FOR   XMAX FOR   YMIN FOR     X FOR      YMAX FOR     X FOR*
 TYPE   TYPE   NO.    CURVE ID.         VALUE         CROSSINGS   ALL DATA   ALL DATA   ALL DATA      YMIN      ALL DATA      YMAX
  PSDF SPCF      3       11(  8)    2.050194E+04  1.620235E+00  1.000E-03  1.000E+01  1.913E+03  1.000E+01  3.430E+08  3.750E-01

                      P R I N T E D   D A T A   F O R   T H I S   C U R V E   F O L L O W S
      S P C F         CURVE   ID =       11      COMPONENT =  8     WHOLE FRAME
                            PRINT NUMBER          X-VALUE             Y-VALUE
                                   1           1.000000E-03         1.977175E+06
                                   2           1.250000E-01         1.799854E+08
                                   3           2.500000E-01         3.194319E+08
                                   4           3.750000E-01         3.430251E+08
                                   5           5.000000E-01         2.358660E+08
                                   6           6.250000E-01         2.040133E+08
                                   7           7.500000E-01         1.502966E+08
                                   8           8.749999E-01         1.317169E+08
                                   9           1.000000E+00         1.073052E+08
                                  10           1.125000E+00         9.854578E+07
                                  11           1.250000E+00         8.739414E+07
                                  12           1.375000E+00         8.483326E+07
                                  13           1.500000E+00         8.128981E+07
                                  14           1.625000E+00         8.399666E+07
                                  15           1.750000E+00         8.699830E+07
                                  16           1.875000E+00         9.632476E+07
                                  17           2.000000E+00         1.074861E+08
                                  18           2.125000E+00         1.253330E+08
                                  19           2.250000E+00         1.414997E+08
                                  20           2.375000E+00         1.512345E+08
                                  21           2.500000E+00         1.386156E+08
                                  22           2.625000E+00         1.119497E+08
                                  23           2.750000E+00         8.302371E+07
                                  24           2.875000E+00         6.315071E+07
                                  25           3.000000E+00         5.134440E+07
                                  26           3.125000E+00         4.643948E+07
                                  27           3.250000E+00         3.439094E+07
                                  28           3.375000E+00         9.975069E+06
                                  29           3.500000E+00         2.071304E+06
                                  30           3.625000E+00         7.829903E+05
                                  31           3.750000E+00         5.397941E+05
                                  32           3.875000E+00         4.577653E+05
                                  33           4.000000E+00         3.951672E+05
                                  34           4.125000E+00         3.398409E+05
                                  35           4.250000E+00         2.875781E+05
                                  36           4.375000E+00         2.429403E+05
                                  37           4.500000E+00         2.035491E+05
                                  38           4.625000E+00         1.711942E+05
                                  39           4.750000E+00         1.434907E+05
                                  40           4.875000E+00         1.210293E+05
                                  41           5.000000E+00         1.019869E+05
                                  42           5.125000E+00         8.657085E+04
                                  43           5.250000E+00         7.352034E+04
                                  44           5.375000E+00         6.292698E+04
                                  45           5.500000E+00         5.394262E+04
                                  46           5.625000E+00         4.662227E+04
                                  47           5.750000E+00         4.039806E+04
                                  48           5.875000E+00         3.531279E+04
                                  49           6.000000E+00         3.098357E+04
                                  50           6.125000E+00         2.744907E+04
                                  51           6.250000E+00         2.444779E+04
                                  52           6.375000E+00         2.201848E+04
                                  53           6.500000E+00         1.998008E+04
                                  54           6.625000E+00         1.837344E+04
                                  55           6.750000E+00         1.707461E+04
                                  56           6.875000E+00         1.613149E+04
                                  57           7.000000E+00         1.546431E+04
                                  58           7.125000E+00         1.513814E+04
                                  59           7.250000E+00         1.511812E+04
                                  60           7.375000E+00         1.551027E+04
                                  61           7.500000E+00         1.635102E+04
                                  62           7.625000E+00         1.784922E+04
                                  63           7.750000E+00         2.020490E+04
                                  64           7.875000E+00         2.390297E+04
                                  65           8.000000E+00         2.952186E+04
                                  66           8.125000E+00         3.787747E+04
                                  67           8.249999E+00         4.850485E+04
                                  68           8.375000E+00         5.632427E+04
                                  69           8.500000E+00         5.172190E+04
                                  70           8.625000E+00         3.718041E+04
                                  71           8.750000E+00         2.371273E+04
                                  72           8.875000E+00         1.499244E+04
                                  73           9.000000E+00         9.803491E+03
                                  74           9.124999E+00         6.728371E+03
                                  75           9.250000E+00         4.843722E+03
                                  76           9.375000E+00         3.664899E+03
                                  77           9.500000E+00         2.907492E+03
                                  78           9.625000E+00         2.425229E+03
                                  79           9.749999E+00         2.121818E+03
                                  80           9.875000E+00         1.970670E+03
                                  81           1.000000E+01         1.913110E+03
```

Frequency Response of BAH Wing to Oscillating Aileron (Examples HA146D and HA146DR)

Each of the four previous dynamic aeroelastic response examples performs a frequency response analysis. This is followed by either a transformation into the time domain via an inverse Fourier transform or by postprocessing of the data for random analysis. The purpose of this example is to demonstrate a straightforward application of the dynamic aeroelastic response capability, which is entirely in the frequency domain, and to outline the restart capability. Both the enforced displacement of the aileron and the output are examined in the frequency domain.

The structural and aerodynamic models are identical to the earlier transient roll model (Example HA146B (p. 667)) but here the enforced displacement is oscillatory. The Lagrange multiplier information, the EPOINT and the DMIG, all related to the loading in the transient roll example, are the same. The only difference here is that the frequency-dependent enforced aileron rotation is input via the RLOAD1 entry in contrast to the TLOAD1 entry required previously for the time history of the transient enforced rotation. RLOAD1 1000 specifies DAREA 1001, which provides the scale factor $A = -1.0$ for the magnitude of the aileron rotation (applied to the EPOINT in the Lagrange multiplier technique), DELAY 1002 and TABLED1 1003 for the frequency response of the enforced rotation.

The frequency response solution is performed over 50 equally spaced intervals with an increment of $\Delta f = 0.1 \text{ Hz}$ for a total range of 5.0 Hz via the FREQ1 40 entry even though TABLED1 covers an input frequency range up to 10.0 Hz. The 5.0 Hz range includes the first three modes determined by the vibration analysis. The first mode is the rigid body roll mode, the second mode is first wing torsion, and third mode is the wing first antisymmetric bending mode. The ENDDATA entry completes the Bulk Data Section.

Case Control Command

The Case Control Section is similar to that for the transient roll example. The K2PP request for the Lagrange multiplier is still required but the TSTEP output request has been deleted and the displacement output request has been replaced with a constraint force output request: SPCF = 1, where SET 1 is the fuselage GRID 11.

The plot request is different from the plot request in HA146B. Here the frequency responses of wing root bending moment and torque are requested in polar form; split frames present the magnitude above the phase angle as functions of the frequency. The constraint force at GRID 11, DOF R3 is the bending moment at the side of the fuselage, and the force at GRID 11, DOF R2 is the torque. The BEGIN BULK entry completes the Case Control Section.

The Executive Control Section identifies the problem as ID MSC, HA146D, which denotes Problem No. HA146D in the Test Problem Library. The time is limited to 10.0 CPU minutes and SOL 146 calls for the dynamic aeroelastic response DMAP sequence. The CEND entry completes the Executive Control Section.

Output

The input data and the sorted Bulk Data entries are shown in Listing 9-10 and Listing 9-11. Selected outputs are in Listing 9-12, Figure 9-10 and Figure 9-11 and are discussed as follows.

The antisymmetric frequencies of the BAH wing are shown first in Listing 9-12. The first frequency is a computed zero for the rigid body roll mode. The second frequency is 3.540 Hz for the first torsion mode, and the third frequency is 4.645 Hz for the first antisymmetric bending mode. The frequency responses for the root shear (T3), the root torque (R2), and the root bending moment (R3) are listed next under COMPLEX FORCES OF SINGLE POINT CONSTRAINT. The root bending moment and torque are plotted in Figure 9-10 and Figure 9-11, respectively. The expected resonances in the frequency response are found in the tabulated and plotted data: the root bending moment peaks near the first bending frequency and the root torque peaks near the first torsion frequency.

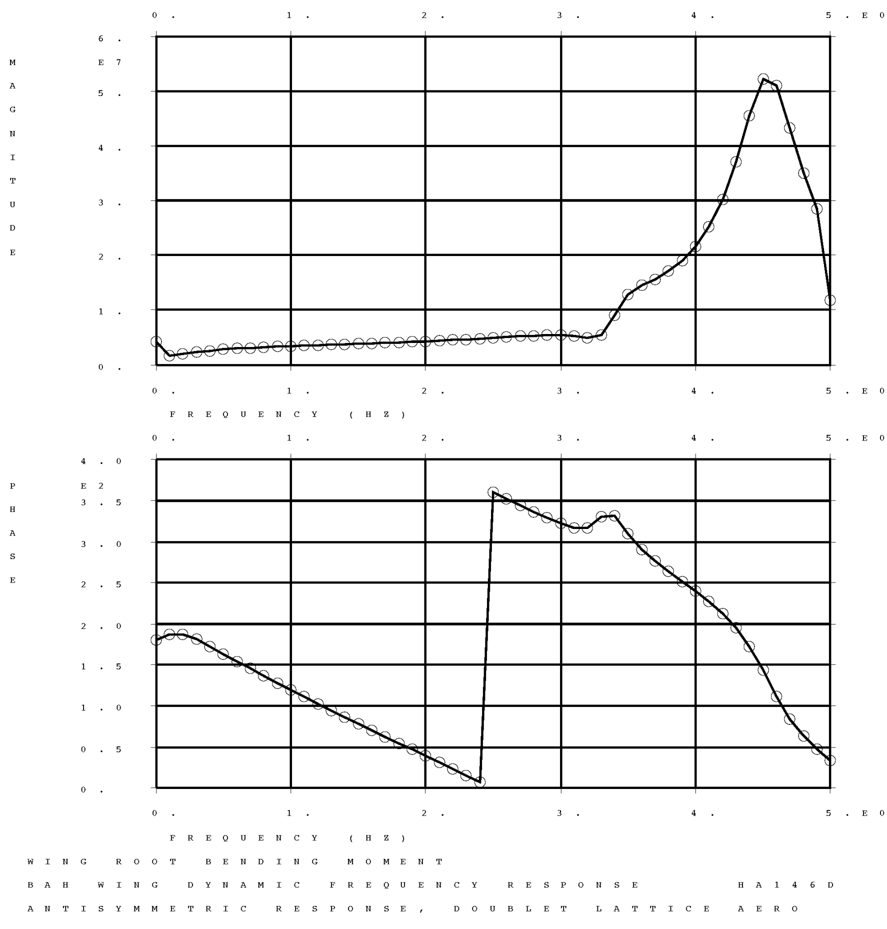


Figure 9-10 Wing Root Bending Moment

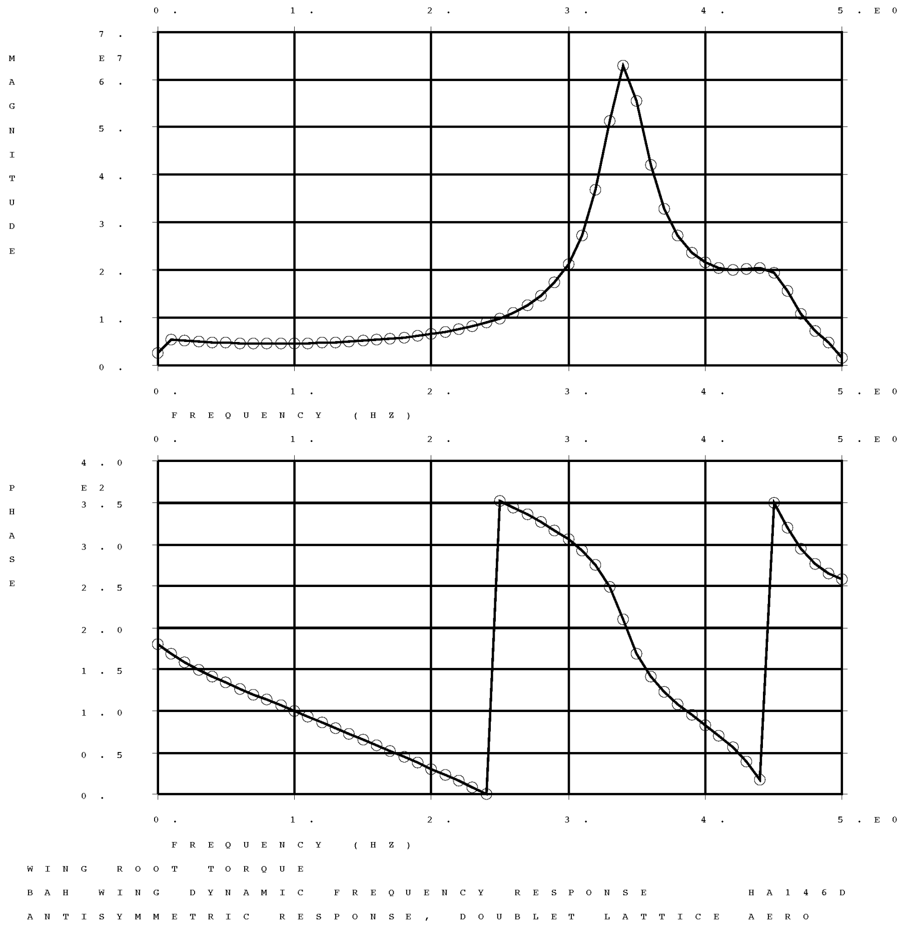


Figure 9-11 Wing Root Torque

This example is very similar to the HA146B example (p. 667) and is therefore a good candidate for the demonstration of the MSC Nastran automatic restart capability (see Restarts, 161). A comparison of the HA146B and HA146D input files shows that the structure, aerodynamic models, and aerodynamic hard points are identical. The same boundary conditions are applied so that the eigenanalysis results (compare Listing 9-6 and Listing 9-12) are identical. Only the loadings differ with HA146B performing a transient roll analysis while the present analysis is for frequency response. The HA146D example can therefore be run as a "restart" of the a HA146B run that has saved its database. The job submittal for the cold start is:

```
nastran ha146b scr=no
```

Listing 9-13 shows the input data file for the restart run and it is seen that the Executive and Case Control Sections are identical to the HA146D file shown in Listing 9-10 with a RESTART command statement added at the top of the listing to indicate that the run is a restart and that it is to use the first "version" of data contained on the database. The Bulk Data Section is minimal in this run and first deletes the loading of the HA146B run by referencing the sorted Bulk Data echo line numbers of Listing 9-5 (the deletion of entries 97 through 101 removes TABLED1, TLOAD1, and TSTEP entries while the deletion of entry 45 removes the FREQ1 request). The subsequent RLOAD1, TABLED1 and FREQ1 entries define the new frequency response loading and are those used for HA146D. The restart run is submitted using

```
nastran ha146d_rst scr=no dbs=ha146b
```

The sorted Bulk Data listing is shown in Listing 9-14. The X-Y output summary from the restart is shown in Listing 9-15, and these results are identical to those shown in Listing 9-12.

Listing 9-10 Input Data for Frequency Response to Oscillating Aileron

```
    N A S T R A N    E X E C U T I V E    C O N T R O L    D E C K    E C H O


ID MSC,HA146D
$$$$$$$$           HANDBOOK FOR AEROELASTIC ANALYSIS EXAMPLE                    $$$$$$$$
$                                                                                      $
$       MODEL DESCRIPTION       BAH JET TRANSPORT WING EXAMPLE                         $
$                               ANTISYMMETRIC RESPONSE TO A                            $
$                               HARMONIC AILERON LOADING                               $
$                                                                                      $
$       SOLUTION                FREQUENCY RESPONSE ANALYSIS USING                      $
$                               DOUBLET LATTICE METHOD AERODYNAMICS                    $
$                               AT MACH NO. OF 0.0                                     $
$                                                                                      $
$       OUTPUT                  XY PLOT OF WING ROOT BENDING MOMENT                    $
$                                                                                      $
$$$$$$$$                                                                         $$$$$$$
TIME  10                   $ CPU TIME IN MINUTES
SOL 146                     $ AEROELASTIC RESPONSE
CEND


     BAH WING DYNAMIC FREQUENCY RESPONSE     HA146D                                                          PAGE     3
      ANTISYMMETRIC RESPONSE, DOUBLET LATTICE AERO
      UNIT HARMONIC AILERON ROTATION

                                        C A S E    C O N T R O L    D E C K    E C H O
                 CARD
                 COUNT
                  1      TITLE = BAH WING DYNAMIC FREQUENCY RESPONSE     HA146D
                  2      SUBTI = ANTISYMMETRIC RESPONSE, DOUBLET LATTICE AERO
                  3      LABEL = UNIT HARMONIC AILERON ROTATION
                  4      ECHO = BOTH
                  5        SPC = 13                  $ BOUNDARY CONDITIONS (ANTISYMMETRIC)
                  6        MPC = 1                   $ CONTROL SURFACE RELATIVE MOTION
                  7        METHOD = 10               $ MODIFIED-GIVENS EIGENVALUE METHOD
                  8        K2PP = ENFORCE            $ EPOINT ADDED VIA DMIG
                  9        SDAMP = 2000              $ STRUCTURAL DAMPING (3 PERCENT)
                 10        DLOAD = 1000              $ FREQUENCY DEPENDENT LOAD
                 11        FREQ = 40                 $ FREQUENCY LIST
                 12      OUTPUT
                 13        SET 1 = 11
                 14        SPCF(PHASE) = 1           $ SINGLE POINT CONSTRAINT FORCES
                 15      OUTPUT(XYOUT)               $ XY PLOTTING PACKAGE
                 16        CSCALE 2.1
                 17        PLOTTER NASTRAN
                 18        TRIGHT TICS = -1
                 19        BRIGHT TICS = -1
                 20        XTGRID = YES
                 21        YTGRID = YES
                 22        XBGRID = YES
                 23        YBGRID = YES
                 24        YTTITLE = MAGNITUDE
                 25        YBTITLE = PHASE
                 26        XTITLE = FREQUENCY (HZ)
                 27        CURVELINESYMBOL = 6
                 28        TCURVE = WING ROOT BENDING MOMENT
                 29        YTITLE = SPC FORCE OF GRID 11 R3
                 30      XYPLOT      SPCF /   11(R3RM,R3IP)
                 31        TCURVE = WING ROOT TORQUE
                 32        YTITLE = SPC FORCE OF GRID 11 R2
                 33      XYPLOT      SPCF /   11(R2RM,R2IP)
                 34      BEGIN BULK
```

Listing 9-10 Input Data for Frequency Response to Oscillating Aileron (Continued)

```
BAH WING DYNAMIC FREQUENCY RESPONSE     HA146D                                                               PAGE     4
 ANTISYMMETRIC RESPONSE, DOUBLET LATTICE AERO

 UNIT HARMONIC AILERON ROTATION
                                I N P U T   B U L K   D A T A   D E C K   E C H O
                         .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                         INCLUDE BAH_STRUCT.DAT
                         $
                         INCLUDE BAH_MASS.DAT
                         $
                         INCLUDE BAH_AILERON
                         $
                         $        TABDMP1 DEFINES DAMPING COEFFICIENTS (G1) VERSES FREQUENCY (F1).
                         $        (3 PERCENT STRUCTURAL DAMPING IS SPECIFIED OVER THE ENTIRE FREQUENCY
                         $        RANGE. VALUES ARE LINEARLY INTERPOLATED AND EXTRAPOLATED. A 3
                         $        PERCENT STRUCTURAL DAMPING IS ROUGHLY EQUIVALENT TO 1.5 PERCENT
                         $        CRITICAL DAMPING).
                         $
                         $       ID      TYPE
                         TABDMP1 2000    G                                                       +T2000
                         $       F1      G1      F2      G2     "ENDT"
                         +T2000  0.      .03     10.     .03     ENDT
                         $
                         $                        * * CONSTRAINTS * *
                         $
                         $        THE SPC ENTRY CONSTRAINS DOFS.
                         $
                         $       SID     G       C       D
                         SPC     13      11      35
                         $
                         $                      * * * AERODYNAMIC DATA * * *
                         $
                         $                (THIS MODEL USES THE LB-IN-SEC SYSTEM)
                         $
                         $                        * * ELEMENT GEOMETRY * *
                         $
                         $        THE AERO ENTRY DEFINES BASIC AERODYNAMIC PARAMETERS. ACSID IS THE
                         $        AERO COORDINATE SYSTEM. VELOCITY. REFC IS THE REFERENECE
                         $        COORDINATE SYSTEM. RHOREF IS REFERENCE DENSITY. SYMXZ AND
                         $        SYMXY ARE SYMMETRY KEYS.
                         $
                         $       ACSID   VELOCITY REFC   RHOREF  SYMXZ   SYMXY
                         AERO    1       8360.   131.25  1.1468-7-1
                         $
                         INCLUDE BAH_AERO58.DAT
                         $
                         $        THE SPLINE1 ENTRY SPECIFIES A SURFACE SPLINE FOR INTERPOLATION
                         $        OVER A REGION (BOX1 THRU BOX2) OF A CAERO PANEL AND THE
                         $        STRUCTURAL GRIDS LISTED ON A SET1 FLAGGED BY SETG.  DZ IS
                         $        A LINEAR ATTACHMENT FLEXIBLITY.
                         $
                         $       EID     CAERO   BOX1    BOX2    SETG    DZ
                         SPLINE1 104     2001    2005    2018    15
                         $
                         $        THE SET1 ENTRY DEFINES THE STRUCTURAL GRID POINTS USED FOR
                         $        INTERPOLATION BY THE SPLINE.
                         $
                         $       SID     G1      G2      G3      G4      G5      G6
                         SET1    15      8       10      12
                         $
                         $        PARAM,M SPECIFIES MACH NUMBER.
                         $
                         PARAM   M       0.0
                         $
                         $        PARAM,Q SPECIFIES DYNAMIC PRESSURE.
                         $
                         PARAM   Q       4.00747
                         $
                         $        THE MKAERO1 ENTRY DEFINES COMBINATIONS OF MACH NUMBER AND REDUCED
                         $        FREQUENCY EACH OF WHICH WILL BE USED TO GENERATE A MATRIX OF
                         $        GENERALIZED AERODYNAMIC FORCES.
                         $
                         $       M1      M2      M3      M4      ETC
                         MKAERO1 0.0                                                             +MK
                         $        K1     K2      K3      K4      ETC
                         +MK     0.001   0.02    0.10    0.50
                         $
                         $* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

Listing 9-10 Input Data for Frequency Response to Oscillating Aileron (Continued)

```
$        THE EPOINT ENTRY DEFINES AN "EXTRA" POINT IN THE STRUCTURAL MODEL.
$        THIS ONE REPRESENTS A LAGRANGE MULTIPLIER FOR THE AILERON HINGE MOMENT.
$
EPOINT  115
$
$                  * * DYNAMIC LOAD AND RESPONSE DATA * *
$
$        RLOAD1 DEFINES A FREQUENCY DEPENDENT DYNAMIC LOAD OR ENFORCED MOTION.
$        LISTED ARE THE ID, DAREA ID, DELAY ID, DPHASE ID, AND TABLEDI IDS.
$
$       SID     DAREA   DELAY   DPHASE  TC      TD
RLOAD1  1000    1001    1002            1003
$
$        DAREA DEFINES THE DOF WHERE THE LOAD IS APPLIED AND A SCALE FACTOR.
$
$       SID     P       C       A
DAREA   1001    115     0       -1.0
$
$        TABLED1 DEFINES A TABULAR FUNCTION OF A TIME-DEPENDENT LOAD.
$
$       SID
TABLED1 1003                                                            +T1003
$       X1      Y1      X2      Y2      ETC.
+T1003  0.      1.      5.      1.      5.      .0      10.     .0      +T1003A
+T1003A ENDT
$
$        THE DELAY ENTRY SPECIFIES THE GRID POINT, DISPLACEMENT COMPONENT
$        AND THE TIME DELAY OF ONSET OF THE FORCING FUNCTION.
$
$       SID     P       C       T
DELAY   1002    115     0       .2
$
$
$        * * * USER SUPPLIED DIRECT MATRIX INPUT DATA * * *
$
$        TIN=1 SPECIFIES THAT THE ELEMENTS WILL BE REAL AND SINGLE PRE-
$        CISION, TOUT=0 SPECIFIES THAT THE TYPE OF MATRIX TO BE GENERATED
$        WILL BE DETERMINED INTERNALLY, POLAR=0 SPECIFIES THAT THE INPUT
$        WILL BE IN ARGAND DIAGRAM FORM (X,IY).
$
$       NAME    "0"     IFO     TIN     TOUT    POLAR           NCOL
DMIG    ENFORCE 0       1       1       0
$
$        G2 AND C2 SPECIFY THAT A PITCHING MOMENT OF 1.0 IN LB BE APPLIED
$        AT THE HINGE-LINE OF THE AILERON.  SEE P. 3.5-9 OF THE "HANDBOOK
$        FOR DYNAMIC ANALYSIS" FOR A DISCUSSION OF LAGRANGE MULTIPLIERS.
$        THE MINUS SIGN ARISES FROM THE DEFINITION OF A POSITIVE AILERON
$        DEFLECTION, that is, TRAILING EDGE DOWN ON THE STARBOARD WING.
$
$       NAME    G1      C1              G2      C2      X21
DMIG    ENFORCE 12      5               115     0       1.
$
$       NAME    G2      C2      X22     G1      C1      X12
DMIG    ENFORCE 115     0               12      5       -1.
$
$* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
$
$        EIGR DEFINES EIGENVALUE EXTRACTION DATA.  LISTED ARE THE
$        EIGENVALUE EXTRACTION METHOD, FREQUENCY RANGE, NUMBER OF
$        EXPECTED AND DESIRED ROOTS AND THE METHOD OF NORMALIZATION.
$
$       SID     METHOD  F1      F2      NE      ND
EIGR    10      MGIV                            12                      +EIGR
$       NORM
+EIGR   MAX
$
$        FREQ1 DEFINES THE SET OF FREQUENCIES USED TO OBTAIN
$        THE FREQUENCY RESPONSE SOLUTION. LISTED ARE THE STARTING
$        FREQUENCY, FREQUENCY INCREMENT AND NUMBER OF INCREMENTS.
$
$       SID     F1      DF      NDF
FREQ1   40      0.      .1      50
$
ENDDATA
INPUT BULK DATA CARD COUNT =     432
```

Listing 9-11 Sorted Bulk Data for Frequency Response to Oscillating Aileron

```
BAH WING DYNAMIC FREQUENCY RESPONSE     HA146D                                                                  PAGE    13
 ANTISYMMETRIC RESPONSE, DOUBLET LATTICE AERO
 UNIT HARMONIC AILERON ROTATION
                                              S O R T E D   B U L K   D A T A   E C H O
               CARD
               COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                  1-        AEFACT  1       0.      .09     .21     .33     .45     .56     .66     +AE1
                  2-        +AE1    .74
                  3-        AEFACT  2       .74     .82     .90     .974
                  4-        AEFACT  3       .974    1.00
                  5-        AEFACT  4       0.      .1875   .375    .625    .750    .875    1.00
                  6-        AERO    1       8360.   131.25  1.1468-7-1
                  7-        CAERO1  1001    1000    0               5       1               1       +CA1
                  8-        +CA1    78.75   0.      0.      225.    35.     500.    0.      100.
                  9-        CAERO1  2001    1000    0                       2       4       1       +CA2
                 10-        +CA2    78.75   0.      0.      225.    35.     500.    0.      100.
                 11-        CAERO1  3001    1000    0               5       3               1       +CA3
                 12-        +CA3    78.75   0.      0.      225.    35.     500.    0.      100.
                 13-        CELAS2  3       5142661.12      5
                 14-        CMASS2  121     5248.7  1       3
                 15-        CMASS2  122     134.9   1       3       2       3
                 16-        CMASS2  123     790.3   2       3
                 17-        CMASS2  341     9727.   3       3
                 18-        CMASS2  342     11005.  3       3       4       3
                 19-        CMASS2  343     473.    4       3
                 20-        CMASS2  561     3253.6  5       3
                 21-        CMASS2  562     -139.7  5       3       6       3
                 22-        CMASS2  563     946.3   6       3
                 23-        CMASS2  781     2617.8  7       3
                 24-        CMASS2  782     21.     7       3       8       3
                 25-        CMASS2  783     782.3   8       3
                 26-        CMASS2  9101    494.8   9       3
                 27-        CMASS2  9102    -7.3    9       3       10      3
                 28-        CMASS2  9103    185.2   10      3
                 29-        CONM1   1       11                                                      +51
                 30-        +51     17400.                          4.37+7                          +52
                 31-        +52             4.35+09
                 32-        CONM1   2       12                                                      +AIL1
                 33-        +AIL1   0.0                                                     0.0     +AIL2
                 34-        +AIL2           13970.5
                 35-        CORD2R  1               0.      0.      0.      0.      0.      -1.     +C1
                 36-        +C1     -1.     0.      0.
                 37-        DAREA   1001    115     0       -1.0
                 38-        DELAY   1002    115     0       .2
                 39-        DMIG    ENFORCE 0       1       1       0
                 40-        DMIG    ENFORCE 12      5               115     0       1.
                 41-        DMIG    ENFORCE 115     0               12      5       -1.
                 42-        EIGR    10      MGIV                            12                      +EIGR
                 43-        +EIGR   MAX
                 44-        EPOINT  115
                 45-        FREQ1   40      0.      .1      50
                 46-        GENEL   432             1       3       2       3       3       3       +01
                 47-        +01     4       3       5       3       6       3       7       3       +02
                 48-        +02     8       3       9       3       10      3                       +03
                 49-        +03     UD              11      3       11      4       11      5       +04
                 50-        +04     11      6                                                       +05
```

Listing 9-11 Sorted Bulk Data for Frequency Response to Oscillating Aileron (Continued)

```
        +05     Z       8.7172-61.3361-61.2778-56.2720-61.6251-51.0492-52.0478-5+06
        +06     1.5630-52.4285-52.0403-53.0861-56.2720-63.2297-51.0492-53.3529-5+07
        +07     1.5630-53.5021-52.0257-53.5785-52.7732-51.5726-54.8255-53.7628-5+08
        +08     7.3284-56.4338-59.5810-58.8378-56.3749-53.7628-58.0136-56.4338-5+09
        +09     1.0012-48.8378-51.1811-41.2758-41.1344-41.9350-41.8160-42.5283-4+10
        +10     2.4294-41.6999-41.8160-42.2920-42.4294-42.8249-43.6862-43.5052-4+11
        +11     5.2675-45.1171-44.2292-45.1171-45.7187-48.4840-48.2340-49.2340-4+12
        +12     S       1.0     90.0    -20.25  45.0    1.0     90.0    81.0    +13
        +13     45.0    1.0     186.0   -17.85  141.0   1.0     186.0   71.4    +14
        +14     141.0   1.0     268.0   -15.80  223.0   1.0     268.0   63.2    +15
        +15     223.0   1.0     368.0   -13.30  323.0   1.0     368.0   53.2    +16
        +16     323.0   1.0     458.0   -11.05  413.0   1.0     458.0   44.2    +17
        +17     413.0
        GRID    1               20.25   90.                     12456
        GRID    2               -81.    90.                     12456
        GRID    3               17.85   186.                    12456
        GRID    4               -71.4   186.                    12456
        GRID    5               15.8    268.                    12456
        GRID    6               -63.2   268.                    12456
        GRID    7               13.3    368.                    12456
        GRID    8               -53.2   368.                    12456
        GRID    9               11.05   458.                    12456
        GRID    10              -44.2   458.                    12456
        GRID    11              0.0     0.                      126
        GRID    12              -86.45  368.                    1246
        MKAERO1 0.0                                                     +MK
        +MK     0.001   0.02    0.10    0.50
        MPC     1       12      3       -1.0    8       3       1.5             +MPC1
        +MPC1           7       3       -0.5    12      5       33.25
        PAERO1  1000
        PARAM   GRDPNT  11
        PARAM   M       0.0
        PARAM   Q       4.00747
        PARAM   WTMASS  .0025907
        RLOAD1  1000    1001    1002            1003
        SET1    14      1       THRU    11
        SET1    15      8       10      12
        SPC     13      11      35
        SPLINE1 104     2001    2005    2018    15
        SPLINE2 101     1001    1001    1035    14      0.      1.      0       +SP1
        +SP1    -1.0    -1.0
        SPLINE2 102     2001    2001    2016    14      0.      1.      0       +SP2
        +SP2    -1.0    -1.0
        SPLINE2 103     3001    3001    3005    14      0.      1.      0       +SP3
        +SP3    -1.0    -1.0
        TABDMP1 2000    G                                               +T2000
        +T2000  0.      .03     10.     .03     ENDT
        TABLED1 1003                                                    +T1003
        +T1003  0.      1.      5.      1.      5.      .0      10.     .0      +T1003A
        +T1003A ENDT
        ENDDATA
  TOTAL COUNT=       101
```

Listing 9-12 Output for Frequency Response to Oscillating Aileron

```
   BAH WING DYNAMIC FREQUENCY RESPONSE     HA146D                                                     PAGE    19
    ANTISYMMETRIC RESPONSE, DOUBLET LATTICE AERO
    UNIT HARMONIC AILERON ROTATION
                                                  R E A L   E I G E N V A L U E S
 MODE    EXTRACTION      EIGENVALUE            RADIANS             CYCLES            GENERALIZED         GENERALIZED
  NO.       ORDER                                                                       MASS              STIFFNESS
     1         1       -6.892265E-13        8.301967E-07        1.321299E-07        1.667624E+01       -1.149371E-11
     2         2        4.945913E+02        2.223941E+01        3.539512E+00        4.167461E+01        2.061190E+04
     3         3        8.508833E+02        2.916990E+01        4.642534E+00        7.082290E+00        6.026202E+03
     4         4        4.434137E+03        6.658932E+01        1.059802E+01        5.831286E+00        2.585672E+04
     5         5        8.732797E+03        9.344943E+01        1.487294E+01        4.022015E+00        3.512344E+04
     6         7        1.501493E+04        1.225354E+02        1.950212E+01        1.220782E+02        1.832996E+06
     7         9        1.766970E+04        1.329274E+02        2.115605E+01        3.908876E+00        6.906864E+04
     8         8        2.409598E+04        1.552288E+02        2.470543E+01        3.522202E+00        8.487088E+04
     9        11        4.211864E+04        2.052283E+02        3.266309E+01        3.142603E+00        1.323622E+05
    10        10        6.020845E+04        2.453741E+02        3.905250E+01        1.016245E+00        6.118652E+04
    11         6        9.304316E+04        3.050298E+02        4.854699E+01        8.852293E+00        8.236453E+05
    12        12        1.420885E+05        3.769462E+02        5.999286E+01        3.619337E+01        5.142661E+06

    POINT-ID =        11

                              C O M P L E X   F O R C E S   O F   S I N G L E   P O I N T   C O N S T R A I N T
                                                         (MAGNITUDE/PHASE)

    FREQUENCY    TYPE          T1                T2                T3              R1                R2              R3
 0.0               G       0.0               0.0               2.885785E+05   0.0              2.497663E+06   4.209172E+06
                           0.0               0.0               0.0            0.0            180.0000       180.0000
 1.000000E-01      G       0.0               0.0               3.462686E+04   0.0              5.341617E+06   1.656624E+06
                           0.0               0.0             358.9044         0.0            169.0537       187.0946
 2.000000E-01      G       0.0               0.0               3.715200E+04   0.0              5.185181E+06   1.976318E+06
                           0.0               0.0             355.5831         0.0            158.8335       186.7975
 3.000000E-01      G       0.0               0.0               4.003538E+04   0.0              4.994818E+06   2.307983E+06
                           0.0               0.0             349.8983         0.0            149.6563       180.9410
 4.000000E-01      G       0.0               0.0               4.263010E+04   0.0              4.818837E+06   2.585938E+06
                           0.0               0.0             342.7689         0.0            141.4345       172.6773
 5.000000E-01      G       0.0               0.0               4.477215E+04   0.0              4.680143E+06   2.803856E+06
                           0.0               0.0             334.9677         0.0            133.9086       163.6324
 6.000000E-01      G       0.0               0.0               4.651321E+04   0.0              4.583896E+06   2.973687E+06
                           0.0               0.0             326.9194         0.0            126.8211       154.4629
 7.000000E-01      G       0.0               0.0               4.795612E+04   0.0              4.527535E+06   3.109103E+06
                           0.0               0.0             318.8221         0.0            119.9813       145.4042
 8.000000E-01      G       0.0               0.0               4.919577E+04   0.0              4.506436E+06   3.221133E+06
                           0.0               0.0             310.7581         0.0            113.2641       136.5240
 9.000000E-01      G       0.0               0.0               5.030629E+04   0.0              4.516295E+06   3.317836E+06
                           0.0               0.0             302.7567         0.0            106.5927       127.8266
 1.000000E+00      G       0.0               0.0               5.134258E+04   0.0              4.553872E+06   3.404923E+06
                           0.0               0.0             294.8237         0.0             99.9220       119.2944
 1.100000E+00      G       0.0               0.0               5.234507E+04   0.0              4.617120E+06   3.486451E+06
                           0.0               0.0             286.9551         0.0             93.2259       110.9041
 1.200000E+00      G       0.0               0.0               5.334400E+04   0.0              4.705084E+06   3.565345E+06
                           0.0               0.0             279.1432         0.0             86.4898       102.6332
 1.300000E+00      G       0.0               0.0               5.436272E+04   0.0              4.817798E+06   3.643771E+06
                           0.0               0.0             271.3799         0.0             79.7055        94.4615
 1.400000E+00      G       0.0               0.0               5.542002E+04   0.0              4.956208E+06   3.723377E+06
                           0.0               0.0             263.6571         0.0             72.8680        86.3716
 1.500000E+00      G       0.0               0.0               5.653175E+04   0.0              5.122163E+06   3.805466E+06
                           0.0               0.0             255.9673         0.0             65.9741        78.3490
 1.600000E+00      G       0.0               0.0               5.771199E+04   0.0              5.318473E+06   3.891096E+06
                           0.0               0.0             248.3040         0.0             59.0207        70.3810
 1.700000E+00      G       0.0               0.0               5.897386E+04   0.0              5.549037E+06   3.981153E+06
                           0.0               0.0             240.6612         0.0             52.0046        62.4572
 1.800000E+00      G       0.0               0.0               6.033011E+04   0.0              5.819067E+06   4.076394E+06
                           0.0               0.0             233.0336         0.0             44.9216        54.5683
 1.900000E+00      G       0.0               0.0               6.179361E+04   0.0              6.135434E+06   4.177455E+06
                           0.0               0.0             225.4163         0.0             37.7659        46.7062
 2.000000E+00      G       0.0               0.0               6.337767E+04   0.0              6.507188E+06   4.284857E+06
                           0.0               0.0             217.8048         0.0             30.5295        38.8639
 2.100000E+00      G       0.0               0.0               6.509627E+04   0.0              6.946306E+06   4.398957E+06
                           0.0               0.0             210.1947         0.0             23.2014        31.0349
 2.200000E+00      G       0.0               0.0               6.696416E+04   0.0              7.468850E+06   4.519882E+06
                           0.0               0.0             202.5821         0.0             15.7665        23.2140
 2.300000E+00      G       0.0               0.0               6.899677E+04   0.0              8.096700E+06   4.647391E+06
                           0.0               0.0             194.9630         0.0              8.2037        15.3965
 2.400000E+00      G       0.0               0.0               7.120993E+04   0.0              8.860268E+06   4.780634E+06
                           0.0               0.0             187.3338         0.0              0.4834         7.5795
```

Listing 9-12 Output for Frequency Response to Oscillating Aileron (Continued)

```
   2.500000E+00     G     0.0            0.0            7.361891E+04  0.0            9.802894E+06   4.917747E+06
                          0.0            0.0          179.6911        0.0          352.5630       359.7631
   2.600000E+00     G     0.0            0.0            7.623647E+04  0.0            1.098824E+07   5.055111E+06
                          0.0            0.0          172.0331        0.0          344.3796       351.9530
   2.700000E+00     G     0.0            0.0            7.906870E+04  0.0            1.251318E+07   5.186022E+06
                          0.0            0.0          164.3605        0.0          335.8372       344.1685
   2.800000E+00     G     0.0            0.0            8.210698E+04  0.0            1.453150E+07   5.298224E+06
                          0.0            0.0          156.6807        0.0          326.7820       336.4601
   2.900000E+00     G     0.0            0.0            8.531131E+04  0.0            1.729956E+07   5.369289E+06
                          0.0            0.0          149.0185        0.0          316.9529       328.9594
   3.000000E+00     G     0.0            0.0            8.857972E+04  0.0            2.126843E+07   5.358764E+06
                          0.0            0.0          141.4457        0.0          305.8746       322.0317
   3.100000E+00     G     0.0            0.0            9.170979E+04  0.0            2.726900E+07   5.202995E+06
                          0.0            0.0          134.1740        0.0          292.6027       316.8169
   3.200000E+00     G     0.0            0.0            9.454148E+04  0.0            3.678848E+07   4.901936E+06
                          0.0            0.0          127.8587        0.0          275.0898       317.2259
   3.300000E+00     G     0.0            0.0            9.895744E+04  0.0            5.121748E+07   5.386076E+06
                          0.0            0.0          124.1503        0.0          248.9234       330.4797
   3.400000E+00     G     0.0            0.0            1.153433E+05  0.0            6.292264E+07   9.125889E+06
                          0.0            0.0          121.4842        0.0          209.5719       331.7407
   3.500000E+00     G     0.0            0.0            1.397750E+05  0.0            5.541844E+07   1.288197E+07
                          0.0            0.0          111.2863        0.0          169.1243       310.0754
   3.600000E+00     G     0.0            0.0            1.569750E+05  0.0            4.209812E+07   1.450235E+07
                          0.0            0.0           99.1698        0.0          141.4372       290.7008
   3.700000E+00     G     0.0            0.0            1.727535E+05  0.0            3.290603E+07   1.566987E+07
                          0.0            0.0           88.2349        0.0          122.6299       276.0620
   3.800000E+00     G     0.0            0.0            1.914614E+05  0.0            2.721831E+07   1.709938E+07
                          0.0            0.0           77.8461        0.0          107.9484       263.6051
   3.900000E+00     G     0.0            0.0            2.153090E+05  0.0            2.368604E+07   1.902751E+07
                          0.0            0.0           67.3816        0.0           95.0518       251.8620
   4.000000E+00     G     0.0            0.0            2.465869E+05  0.0            2.153033E+07   2.165180E+07
                          0.0            0.0           56.3640        0.0           82.6988       239.9876
   4.100000E+00     G     0.0            0.0            2.885493E+05  0.0            2.035072E+07   2.525212E+07
                          0.0            0.0           44.2614        0.0           69.9875       227.2745
   4.200000E+00     G     0.0            0.0            3.458575E+05  0.0            1.993973E+07   3.023772E+07
                          0.0            0.0           30.2835        0.0           55.9403       212.8407
   4.300000E+00     G     0.0            0.0            4.235863E+05  0.0            2.011624E+07   3.706418E+07
                          0.0            0.0           13.1206        0.0           39.1570       195.3249
   4.400000E+00     G     0.0            0.0            5.187861E+05  0.0            2.037909E+07   4.549716E+07
                          0.0            0.0          350.7889        0.0           17.6234       172.7120
   4.500000E+00     G     0.0            0.0            5.933007E+05  0.0            1.930026E+07   5.221080E+07
                          0.0            0.0          321.9275        0.0          349.9944       143.6212
   4.600000E+00     G     0.0            0.0            5.778406E+05  0.0            1.554109E+07   5.107458E+07
                          0.0            0.0          290.1584        0.0          319.9532       111.6617
   4.700000E+00     G     0.0            0.0            4.870178E+05  0.0            1.078277E+07   4.327256E+07
                          0.0            0.0          262.7525        0.0          294.8864        84.0952
   4.800000E+00     G     0.0            0.0            3.911368E+05  0.0            7.079736E+06   3.496078E+07
                          0.0            0.0          241.8658        0.0          277.1436        63.0714
   4.900000E+00     G     0.0            0.0            3.165107E+05  0.0            4.640559E+06   2.847766E+07
                          0.0            0.0          225.7154        0.0          265.2546        46.8027
   5.000000E+00     G     0.0            0.0            1.309741E+05  0.0            1.539469E+06   1.186908E+07
                          0.0            0.0          212.4672        0.0          257.8848        33.4515

                                   X Y - O U T P U T   S U M M A R Y   ( R E S P O N S E )
 SUBCASE  CURVE  FRAME                     XMIN-FRAME/    XMAX-FRAME/    YMIN-FRAME/     X FOR          YMAX-FRAME/     X FOR
   ID      TYPE   NO.      CURVE ID.         ALL DATA       ALL DATA       ALL DATA        YMIN            ALL DATA       YMAX
     1    SPCF     1         11(   8,--)   0.000000E+00   5.000000E+00   1.656624E+06   1.000000E-01   5.221080E+07   4.500000E+00
                                           0.000000E+00   5.000000E+00   1.656624E+06   1.000000E-01   5.221080E+07   4.500000E+00
     1    SPCF     1         11(--, 14)    0.000000E+00   5.000000E+00   7.579535E+00   2.400000E+00   3.597631E+02   2.500000E+00
                                           0.000000E+00   5.000000E+00   7.579535E+00   2.400000E+00   3.597631E+02   2.500000E+00
     1    SPCF     2         11(   7,--)   0.000000E+00   5.000000E+00   1.539469E+06   5.000000E+00   6.292264E+07   3.400000E+00
                                           0.000000E+00   5.000000E+00   1.539469E+06   5.000000E+00   6.292264E+07   3.400000E+00
     1    SPCF     2         11(--, 13)    0.000000E+00   5.000000E+00   4.834088E-01   2.400000E+00   3.525630E+02   2.500000E+00
                                           0.000000E+00   5.000000E+00   4.834088E-01   2.400000E+00   3.525630E+02   2.500000E+00
```

Listing 9-13 Input Data for Frequency Response to Oscillating Aileron via Restart

```
    N A S T R A N    F I L E    M A N A G E M E N T    S E C T I O N    E C H O


RESTART VERSION=1,KEEP
                                                                                                                            PAGE     2

    N A S T R A N    E X E C U T I V E    C O N T R O L    D E C K    E C H O


ID MSC,HA146DR
$$$$$$$$           HANDBOOK FOR AEROELASTIC ANALYSIS EXAMPLE                    $$$$$$$$
$                                                                                      $
$       MODEL DESCRIPTION       BAH JET TRANSPORT WING EXAMPLE                         $
$                               ANTISYMMETRIC RESPONSE TO A                            $
$                               HARMONIC AILERON LOADING                               $
$                                                                                      $
$       SOLUTION                FREQUENCY RESPONSE ANALYSIS USING                      $
$                               DOUBLET LATTICE METHOD AERODYNAMICS                    $
$                               AT MACH NO. OF 0.0                                     $
$                                                                                      $
$       OUTPUT                  XY PLOT OF WING ROOT BENDING MOMENT                    $
$                                                                                      $
$$$$$$$$                                                                         $$$$$$$
TIME  10                  $ CPU TIME IN MINUTES
SOL 146                    $ AEROELASTIC RESPONSE
CEND

BAH WING DYNAMIC FREQUENCY RESPONSE     HA146DR                                                                 PAGE     3
 ANTISYMMETRIC RESPONSE, DOUBLET LATTICE AERO
 UNIT HARMONIC AILERON ROTATION

                                   C A S E    C O N T R O L    D E C K    E C H O

            CARD
            COUNT
             1      TITLE = BAH WING DYNAMIC FREQUENCY RESPONSE     HA146DR
             2      SUBTI = ANTISYMMETRIC RESPONSE, DOUBLET LATTICE AERO
             3      LABEL = UNIT HARMONIC AILERON ROTATION
             4      ECHO = BOTH
             5        SPC = 13                  $ BOUNDARY CONDITIONS (ANTISYMMETRIC)
             6        MPC = 1                   $ CONTROL SURFACE RELATIVE MOTION
             7        METHOD = 10               $ MODIFIED-GIVENS EIGENVALUE METHOD
             8        K2PP = ENFORCE            $ EPOINT ADDED VIA DMIG
             9        SDAMP = 2000              $ STRUCTURAL DAMPING (3 PERCENT)
            10        DLOAD = 1000              $ FREQUENCY DEPENDENT LOAD
            11        FREQ = 40                 $ FREQUENCY LIST
            12      OUTPUT
            13        SET 1 = 11
            14        SPCF(PHASE) = 1           $ SINGLE POINT CONSTRAINT FORCES
            15      OUTPUT(XYOUT)               $ XY PLOTTING PACKAGE
            16        CSCALE 2.1
            17        PLOTTER NASTRAN
            18        TRIGHT TICS = -1
            19        BRIGHT TICS = -1
            20        XTGRID = YES
            21        YTGRID = YES
            22        XBGRID = YES
            23        YBGRID = YES
            24        YTTITLE = MAGNITUDE
            25        YBTITLE = PHASE
            26        XTITLE = FREQUENCY (HZ)
            27        CURVELINESYMBOL = 6
            28        TCURVE = WING ROOT BENDING MOMENT
            29        YTITLE = SPC FORCE OF GRID 11 R3
            30      XYPLOT      SPCF /   11(R3RM,R3IP)
            31        TCURVE = WING ROOT TORQUE
            32        YTITLE = SPC FORCE OF GRID 11 R2
            33      XYPLOT      SPCF /   11(R2RM,R2IP)
            34      BEGIN BULK
```

```
BAH WING DYNAMIC FREQUENCY RESPONSE     HA146DR                                                           PAGE     4
 ANTISYMMETRIC RESPONSE, DOUBLET LATTICE AERO
 UNIT HARMONIC AILERON ROTATION

                                        I N P U T   B U L K   D A T A   D E C K   E C H O

                         .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                         /       97      101
                         /       45
                         $
                         $                  * * DYNAMIC LOAD AND RESPONSE DATA * *
                         $
                         $        RLOAD1 DEFINES A FREQUENCY DEPENDENT DYNAMIC LOAD OR ENFORCED MOTION.
                         $        LISTED ARE THE ID, DAREA ID, DELAY ID, DPHASE ID, AND TABLEDI IDS.
                         $
                         $       SID     DAREA   DELAY   DPHASE  TC      TD
                         RLOAD1  1000    1001    1002            1003
                         $
                         $
                         $        TABLED1 DEFINES A TABULAR FUNCTION OF A TIME-DEPENDENT LOAD.
                         $
                         $       SID
                         TABLED1 1003                                                            +T1003
                         $       X1      Y1      X2      Y2      ETC.
                         +T1003  0.      1.      5.      1.      5.      .0      10.     .0      +T1003A
                         +T1003A ENDT
                         $
                         $        FREQ1 DEFINES THE SET OF FREQUENCIES USED TO OBTAIN
                         $        THE FREQUENCY RESPONSE SOLUTION. LISTED ARE THE STARTING
                         $        FREQUENCY, FREQUENCY INCREMENT AND NUMBER OF INCREMENTS.
                         $
                         $       SID     F1      DF      NDF
                         FREQ1   40      0.      .1      50
                         $
                         $
                         ENDDATA
                         INPUT BULK DATA CARD COUNT =      29
```

Listing 9-14 Sorted Bulk Data for Frequency Response to Oscillating Aileron via Restart

```
BAH WING DYNAMIC FREQUENCY RESPONSE     HA146DR                                                                 PAGE     5
 ANTISYMMETRIC RESPONSE, DOUBLET LATTICE AERO
 UNIT HARMONIC AILERON ROTATION

                                                    S O R T E D   B U L K   D A T A   E C H O

           CARD
           COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
              1-        AEFACT  1       0.      .09     .21     .33     .45     .56     .66     +AE1
              2-        +AE1    .74
              3-        AEFACT  2       .74     .82     .90     .974
              4-        AEFACT  3       .974    1.00
              5-        AEFACT  4       0.      .1875   .375    .625    .750    .875    1.00
              6-        AERO    1       8360.   131.232 1.1468-7-1
              7-        CAERO1  1001    1000    0               5       1               1       +CA1
              8-        +CA1    78.75   0.      0.      225.    35.     500.    0.      100.
              9-        CAERO1  2001    1000    0                       2       4       1       +CA2
             10-        +CA2    78.75   0.      0.      225.    35.     500.    0.      100.
             11-        CAERO1  3001    1000    0               5       3               1       +CA3
             12-        +CA3    78.75   0.      0.      225.    35.     500.    0.      100.
             13-        CELAS2  3       5142661.12      5
             14-        CMASS2  121     5248.7  1       3
             15-        CMASS2  122     134.9   1       3       2       3
             16-        CMASS2  123     790.3   2       3
             17-        CMASS2  341     9727.   3       3
             18-        CMASS2  342     11005.  3       3       4       3
             19-        CMASS2  343     473.    4       3
             20-        CMASS2  561     3253.6  5       3
             21-        CMASS2  562     -139.7  5       3       6       3
             22-        CMASS2  563     946.3   6       3
             23-        CMASS2  781     2617.8  7       3
             24-        CMASS2  782     21.     7       3       8       3
             25-        CMASS2  783     782.3   8       3
             26-        CMASS2  9101    494.8   9       3
             27-        CMASS2  9102    -7.3    9       3       10      3
             28-        CMASS2  9103    185.2   10      3
             29-        CONM1   1       11                                                      +51
             30-        +51     17400.                          4.37+7                          +52
             31-        +52             4.35+09
             32-        CONM1   2       12                                                      +AIL1
             33-        +AIL1   0.0                                                     0.0     +AIL2
             34-        +AIL2           13970.5
             35-        CORD2R  1               0.      0.      0.      0.      0.      -1.     +C1
             36-        +C1     -1.     0.      0.
             37-        DAREA   1001    115     0       -1.0
             38-        DELAY   1002    115     0       .2
             39-        DMIG    ENFORCE 0       1       1       0
             40-        DMIG    ENFORCE 12      5               115     0       1.
             41-        DMIG    ENFORCE 115     0               12      5       -1.
             42-        EIGR    10      MGIV                            12                      +EIGR
             43-        +EIGR   MAX
             44-        EPOINT  115
             45-        FREQ1   40      0.      .1      50
             46-        GENEL   432             1       3       2       3       3       3       +01
             47-        +01     4       3       5       3       6       3       7       3       +02
             48-        +02     8       3       9       3       10      3                       +03
             49-        +03     UD              11      3       11      4       11      5       +04
             50-        +04     11      6                                                       +05
```

Listing 9-14 Sorted Bulk Data for Frequency Response to Oscillating Aileron via Restart (Continued)

```
BAH WING DYNAMIC FREQUENCY RESPONSE     HA146DR                                                               PAGE     6
 ANTISYMMETRIC RESPONSE, DOUBLET LATTICE AERO
 UNIT HARMONIC AILERON ROTATION

                                              S O R T E D   B U L K   D A T A   E C H O

            CARD
            COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
              51-        +05     Z       8.7172-61.3361-61.2778-56.2720-61.6251-51.0492-52.0478-5+06
              52-        +06     1.5630-52.4285-52.0403-53.0861-56.2720-63.2297-51.0492-53.3529-5+07
              53-        +07     1.5630-53.5021-52.0257-53.5785-52.7732-51.5726-54.8255-53.7628-5+08
              54-        +08     7.3284-56.4338-59.5810-58.8378-56.3749-53.7628-58.0136-56.4338-5+09
              55-        +09     1.0012-48.8378-51.1811-41.2758-41.1344-41.9350-41.8160-42.5283-4+10
              56-        +10     2.4294-41.6999-41.8160-42.2920-42.4294-42.8249-43.6862-43.5052-4+11
              57-        +11     5.2675-45.1171-44.2292-45.1171-45.7187-48.4840-48.2340-49.2340-4+12
              58-        +12     S       1.0     90.0    -20.25  45.0    1.0     90.0    81.0    +13
              59-        +13     45.0    1.0     186.0   -17.85  141.0   1.0     186.0   71.4    +14
              60-        +14     141.0   1.0     268.0   -15.80  223.0   1.0     268.0   63.2    +15
              61-        +15     223.0   1.0     368.0   -13.30  323.0   1.0     368.0   53.2    +16
              62-        +16     323.0   1.0     458.0   -11.05  413.0   1.0     458.0   44.2    +17
              63-        +17     413.0
              64-        GRID    1               20.25   90.                     12456
              65-        GRID    2               -81.    90.                     12456
              66-        GRID    3               17.85   186.                    12456
              67-        GRID    4               -71.4   186.                    12456
              68-        GRID    5               15.8    268.                    12456
              69-        GRID    6               -63.2   268.                    12456
              70-        GRID    7               13.3    368.                    12456
              71-        GRID    8               -53.2   368.                    12456
              72-        GRID    9               11.05   458.                    12456
              73-        GRID    10              -44.2   458.                    12456
              74-        GRID    11              0.0     0.                      126
              75-        GRID    12              -86.45  368.                    1246
              76-        MKAERO1 0.0                                                             +MK
              77-        +MK     0.001   0.02    0.10    0.50
              78-        MPC     1       12      3       -1.0    8       3       1.5             +MPC1
              79-        +MPC1           7       3       -0.5    12      5       33.25
              80-        PAERO1  1000
              81-        PARAM   GRDPNT  11
              82-        PARAM   LMODES  12
              83-        PARAM   Q       4.00747
              84-        PARAM   WTMASS  .0025907
              85-        RLOAD1  1000    1001    1002            1003
              86-        SET1    14      1       THRU    11
              87-        SET1    15      8       10      12
              88-        SPC     13      11      35
              89-        SPLINE1 104     2001    2005    2018    15
              90-        SPLINE2 101     1001    1001    1035    14      0.      1.      0       +SP1
              91-        +SP1    -1.0    -1.0
              92-        SPLINE2 102     2001    2001    2016    14      0.      1.      0       +SP2
              93-        +SP2    -1.0    -1.0
              94-        SPLINE2 103     3001    3001    3005    14      0.      1.      0       +SP3
              95-        +SP3    -1.0    -1.0
              96-        TABDMP1 2000                                                            +T2000
              97-        +T2000  0.      .03     10.     .03     ENDT
              98-        TABLED1 1003                                                            +T1003
              99-        +T1003  0.      1.      5.      1.      5.      .0      10.     .0      +T1003A
             100-        +T1003A ENDT
                         ENDDATA
                  TOTAL COUNT=       101
```

Listing 9-15 Output for Frequency response to Oscillating Aileron via Restart

```
   BAH WING DYNAMIC FREQUENCY RESPONSE     HA146DR                                                           PAGE     7
    ANTISYMMETRIC RESPONSE, DOUBLET LATTICE AERO
    UNIT HARMONIC AILERON ROTATION
    POINT-ID =      11

                     C O M P L E X   F O R C E S   O F   S I N G L E   P O I N T   C O N S T R A I N T
                                                (MAGNITUDE/PHASE)

    FREQUENCY    TYPE         T1             T2             T3             R1             R2             R3
 0.0              G     0.0            0.0            2.885140E+05   0.0            2.497399E+06   4.208535E+06
                          0.0            0.0            0.0            0.0          180.0000       180.0000
 1.000000E-01     G     0.0            0.0            3.462687E+04   0.0            5.341615E+06   1.656625E+06
                          0.0            0.0          358.9045         0.0          169.0536       187.0946
 2.000000E-01     G     0.0            0.0            3.715199E+04   0.0            5.185183E+06   1.976318E+06
                          0.0            0.0          355.5831         0.0          158.8336       186.7975
 3.000000E-01     G     0.0            0.0            4.003538E+04   0.0            4.994818E+06   2.307983E+06
                          0.0            0.0          349.8983         0.0          149.6563       180.9410
 4.000000E-01     G     0.0            0.0            4.263010E+04   0.0            4.818835E+06   2.585938E+06
                          0.0            0.0          342.7689         0.0          141.4345       172.6773
 5.000000E-01     G     0.0            0.0            4.477215E+04   0.0            4.680143E+06   2.803856E+06
                          0.0            0.0          334.9677         0.0          133.9086       163.6324
 6.000000E-01     G     0.0            0.0            4.651322E+04   0.0            4.583895E+06   2.973687E+06
                          0.0            0.0          326.9194         0.0          126.8211       154.4629
 7.000000E-01     G     0.0            0.0            4.795611E+04   0.0            4.527534E+06   3.109102E+06
                          0.0            0.0          318.8221         0.0          119.9813       145.4042
 8.000000E-01     G     0.0            0.0            4.919577E+04   0.0            4.506437E+06   3.221134E+06
                          0.0            0.0          310.7581         0.0          113.2641       136.5241
 9.000000E-01     G     0.0            0.0            5.030629E+04   0.0            4.516294E+06   3.317836E+06
                          0.0            0.0          302.7567         0.0          106.5927       127.8266
 1.000000E+00     G     0.0            0.0            5.134258E+04   0.0            4.553871E+06   3.404923E+06
                          0.0            0.0          294.8237         0.0           99.9220       119.2944
 1.100000E+00     G     0.0            0.0            5.234507E+04   0.0            4.617120E+06   3.486451E+06
                          0.0            0.0          286.9551         0.0           93.2259       110.9041
 1.200000E+00     G     0.0            0.0            5.334401E+04   0.0            4.705084E+06   3.565346E+06
                          0.0            0.0          279.1433         0.0           86.4898       102.6332
 1.300000E+00     G     0.0            0.0            5.436272E+04   0.0            4.817797E+06   3.643771E+06
                          0.0            0.0          271.3799         0.0           79.7055        94.4615
 1.400000E+00     G     0.0            0.0            5.542002E+04   0.0            4.956208E+06   3.723378E+06
                          0.0            0.0          263.6571         0.0           72.8680        86.3716
 1.500000E+00     G     0.0            0.0            5.653175E+04   0.0            5.122164E+06   3.805467E+06
                          0.0            0.0          255.9673         0.0           65.9741        78.3490
 1.600000E+00     G     0.0            0.0            5.771199E+04   0.0            5.318474E+06   3.891096E+06
                          0.0            0.0          248.3040         0.0           59.0207        70.3811
 1.700000E+00     G     0.0            0.0            5.897385E+04   0.0            5.549038E+06   3.981154E+06
                          0.0            0.0          240.6612         0.0           52.0046        62.4572
 1.800000E+00     G     0.0            0.0            6.033011E+04   0.0            5.819067E+06   4.076394E+06
                          0.0            0.0          233.0336         0.0           44.9216        54.5683
 1.900000E+00     G     0.0            0.0            6.179360E+04   0.0            6.135434E+06   4.177455E+06
                          0.0            0.0          225.4163         0.0           37.7659        46.7062
 2.000000E+00     G     0.0            0.0            6.337767E+04   0.0            6.507188E+06   4.284857E+06
                          0.0            0.0          217.8048         0.0           30.5295        38.8639
 2.100000E+00     G     0.0            0.0            6.509627E+04   0.0            6.946305E+06   4.398956E+06
                          0.0            0.0          210.1948         0.0           23.2014        31.0350
 2.200000E+00     G     0.0            0.0            6.696414E+04   0.0            7.468850E+06   4.519881E+06
                          0.0            0.0          202.5822         0.0           15.7665        23.2140
 2.300000E+00     G     0.0            0.0            6.899676E+04   0.0            8.096700E+06   4.647391E+06
                          0.0            0.0          194.9631         0.0            8.2037        15.3965
 2.400000E+00     G     0.0            0.0            7.120991E+04   0.0            8.860268E+06   4.780633E+06
                          0.0            0.0          187.3338         0.0            0.4834         7.5796
 2.500000E+00     G     0.0            0.0            7.361890E+04   0.0            9.802895E+06   4.917747E+06
                          0.0            0.0          179.6912         0.0          352.5630       359.7631
 2.600000E+00     G     0.0            0.0            7.623645E+04   0.0            1.098824E+07   5.055110E+06
                          0.0            0.0          172.0331         0.0          344.3796       351.9530
 2.700000E+00     G     0.0            0.0            7.906869E+04   0.0            1.251318E+07   5.186022E+06
                          0.0            0.0          164.3605         0.0          335.8372       344.1685
 2.800000E+00     G     0.0            0.0            8.210696E+04   0.0            1.453150E+07   5.298223E+06
                          0.0            0.0          156.6807         0.0          326.7820       336.4601
 2.900000E+00     G     0.0            0.0            8.531130E+04   0.0            1.729956E+07   5.369287E+06
                          0.0            0.0          149.0186         0.0          316.9529       328.9594
 3.000000E+00     G     0.0            0.0            8.857969E+04   0.0            2.126843E+07   5.358762E+06
                          0.0            0.0          141.4457         0.0          305.8746       322.0317
 3.100000E+00     G     0.0            0.0            9.170978E+04   0.0            2.726901E+07   5.202992E+06
                          0.0            0.0          134.1740         0.0          292.6028       316.8169
 3.200000E+00     G     0.0            0.0            9.454145E+04   0.0            3.678849E+07   4.901927E+06
                          0.0            0.0          127.8586         0.0          275.0900       317.2258
```

Listing 9-15 Output for Frequency response to Oscillating Aileron via Restart (Continued)

```
3.300000E+00     G     0.0            0.0            9.895737E+04   0.0            5.121757E+07   5.386052E+06
                         0.0            0.0          124.1502         0.0          248.9236       330.4798
3.400000E+00     G     0.0            0.0            1.153431E+05   0.0            6.292292E+07   9.125871E+06
                         0.0            0.0          121.4843         0.0          209.5720       331.7410
3.500000E+00     G     0.0            0.0            1.397748E+05   0.0            5.541867E+07   1.288197E+07
                         0.0            0.0          111.2863         0.0          169.1242       310.0756
3.600000E+00     G     0.0            0.0            1.569748E+05   0.0            4.209824E+07   1.450235E+07
                         0.0            0.0           99.1699         0.0          141.4371       290.7009
3.700000E+00     G     0.0            0.0            1.727534E+05   0.0            3.290609E+07   1.566986E+07
                         0.0            0.0           88.2349         0.0          122.6298       276.0621
3.800000E+00     G     0.0            0.0            1.914612E+05   0.0            2.721834E+07   1.709937E+07
                         0.0            0.0           77.8461         0.0          107.9483       263.6051
3.900000E+00     G     0.0            0.0            2.153087E+05   0.0            2.368606E+07   1.902749E+07
                         0.0            0.0           67.3816         0.0           95.0517       251.8620
4.000000E+00     G     0.0            0.0            2.465867E+05   0.0            2.153034E+07   2.165179E+07
                         0.0            0.0           56.3641         0.0           82.6988       239.9877
4.100000E+00     G     0.0            0.0            2.885489E+05   0.0            2.035072E+07   2.525210E+07
                         0.0            0.0           44.2615         0.0           69.9875       227.2746
4.200000E+00     G     0.0            0.0            3.458573E+05   0.0            1.993974E+07   3.023770E+07
                         0.0            0.0           30.2835         0.0           55.9403       212.8408
4.300000E+00     G     0.0            0.0            4.235860E+05   0.0            2.011624E+07   3.706416E+07
                         0.0            0.0           13.1207         0.0           39.1570       195.3250
4.400000E+00     G     0.0            0.0            5.187858E+05   0.0            2.037910E+07   4.549714E+07
                         0.0            0.0          350.7890         0.0           17.6234       172.7121
4.500000E+00     G     0.0            0.0            5.933006E+05   0.0            1.930028E+07   5.221080E+07
                         0.0            0.0          321.9276         0.0          349.9944       143.6213
4.600000E+00     G     0.0            0.0            5.778407E+05   0.0            1.554111E+07   5.107459E+07
                         0.0            0.0          290.1585         0.0          319.9532       111.6618
4.700000E+00     G     0.0            0.0            4.870179E+05   0.0            1.078278E+07   4.327257E+07
                         0.0            0.0          262.7526         0.0          294.8865        84.0953
4.800000E+00     G     0.0            0.0            3.911369E+05   0.0            7.079745E+06   3.496079E+07
                         0.0            0.0          241.8659         0.0          277.1437        63.0714
4.900000E+00     G     0.0            0.0            3.165107E+05   0.0            4.640564E+06   2.847766E+07
                         0.0            0.0          225.7155         0.0          265.2547        46.8027
5.000000E+00     G     0.0            0.0            1.309742E+05   0.0            1.539471E+06   1.186908E+07
                         0.0            0.0          212.4672         0.0          257.8848        33.4515
                                    X Y - O U T P U T   S U M M A R Y   ( R E S P O N S E )

SUBCASE  CURVE  FRAME                XMIN-FRAME/    XMAX-FRAME/    YMIN-FRAME/     X FOR          YMAX-FRAME/     X FOR
  ID      TYPE   NO.    CURVE ID.     ALL DATA       ALL DATA       ALL DATA        YMIN           ALL DATA        YMAX
    1   SPCF     1      11(  8,--)  0.000000E+00   5.000000E+00   1.656625E+06   1.000000E-01   5.221080E+07   4.500000E+00
                                    0.000000E+00   5.000000E+00   1.656625E+06   1.000000E-01   5.221080E+07   4.500000E+00
    1   SPCF     1      11(--, 14)  0.000000E+00   5.000000E+00   7.579554E+00   2.400000E+00   3.597631E+02   2.500000E+00
                                    0.000000E+00   5.000000E+00   7.579554E+00   2.400000E+00   3.597631E+02   2.500000E+00
    1   SPCF     2      11(  7,--)  0.000000E+00   5.000000E+00   1.539471E+06   5.000000E+00   6.292292E+07   3.400000E+00
                                    0.000000E+00   5.000000E+00   1.539471E+06   5.000000E+00   6.292292E+07   3.400000E+00
    1   SPCF     2      11(--, 13)  0.000000E+00   5.000000E+00   4.834216E-01   2.400000E+00   3.525630E+02   2.500000E+00
                                    0.000000E+00   5.000000E+00   4.834216E-01   2.400000E+00   3.525630E+02   2.500000E+00
```

Subsonic Transient Response Analysis of a Sweptback Wing to an Impulsive Force Applied at the Tip (Example HA146E)

This example is the same model of the sweptback wing that was used in the flutter analysis of Example HA145E (p. 469) with an impulsive load now applied at the wing tip. The flutter speed of this model, determined by Example HA145E, is 491 ft/s = 5892 in/s and is one of these velocities at which this analysis is performed. Analyses are also performed at velocities above and below the flutter speed.

The structural model and the aerodynamic model are the same as those described in the flutter analysis of Example HA145E as are the root mounting conditions. A four mode solution is again used in order to have the identical flutter speed. The new loading entries are discussed below.

The TLOAD1 10 entry specifies the DAREA 12, DELAY 13, and TABLED1 14 entries that define the impulsive loading. The loading is applied at GRID 40 at the tip trailing edge of the wing in the positive z-direction. A frequency interval of $\Delta f = 5.0 \text{ Hz}$ is selected and results in a period $T = 1/\Delta f = 0.2 \text{ seconds}$. A 0.1 second delay (that is, half the period) is specified on the DELAY entry before the impulse is applied so that the response for a complete period need not be calculated; however, two full cycles are calculated here to illustrate the complete behavior of the Fourier solution in the three cases of stability (below the flutter speed), neutral stability (at the flutter speed), and instability (above the flutter speed). The unit impulse (the area under the curve is 1.0) is applied for 10^{-6} seconds with a force of 10^{6} lbs. The unit impulse is followed by a second impulse that is equal in magnitude but opposite in sign. As explained in Example HA146A (p. 650), certain output, such as stresses, will now tend to a zero value; however, in this example of a cantilever wing, the deflections will also approach zero.

Three analyses are performed on the swept wing at three different speeds. The data input files are different only in the velocity on the AERO entry and in the corresponding dynamic pressure defined by PARAM,Q. The velocities are 450.0, 491.0 (the flutter speed), and 530.0 ft/s and the corresponding dynamic pressures based on the wind tunnel test density of 0.0023 slugs/cu. ft. are 1.617, 1.925, and 2.343 psi, respectively. The ENDDATA entry completes the Bulk Data Section.

Case Control Commands

The Case Control Section contains the TITLE, SUBTITLE, and LABEL commands. ECHO = BOTH echoes back all of the Bulk Data. SPC = 1 selects the boundary conditions, METHOD = 10 selects the EIGR entry for the vibration analysis, SDAMP = 2000 selects the damping, DLOAD = 10 selects the impulsive load, FREQ = 101 selects the frequency list and TSTEP = 201 selects the time history output. The DISP command specifies that displacements of GRID 40 be calculated and printed. Following OUTPUT(XYOUT) is an xy-plot request. Preceding the plot request are several optional statements that define the plot frame and plot titles. An XYPLOT is requested for the tip displacement of the wing at GRID 40 in the z-direction. The BEGIN BULK command completes the Case Control Section.

The Executive Control Section lists the identification as ID MSC, HA146E, which denotes Problem No. HA146E in the Test Problem Library. TIME 10 limits the CPU to 10.0 minutes. SOL 146 is the Dynamic Aeroelastic Response solution sequence. The CEND statement completes the Executive Control Section.

The input data are shown in Listing 9-16, the sorted Bulk Data are in Listing 9-17, and selected output are in Listing 9-18. The output is discussed briefly below.

Figure 9-12 is from the analysis performed at 450 ft/s = 5400 in/s. Since there is a 0.1 sec delay, the first full period plotted is from 0.1 to 0.3 seconds. The responses from 0.0 to 0.1 seconds and from 0.2 to 0.3 seconds represent the same portions of separate periods. Figure 9-12 shows, that below the flutter speed, the tip displacement peaks immediately and then damps out to negligible values in about 0.1 sec. This type of stable behavior is expected below the flutter speed.

Figure 9-13 is from the analysis performed at the flutter speed of 491 ft/s = 5892 in/s and shows that the same impulsive load first excites a stable mode, which damps out, followed by an unstable mode that appears as a divergent oscillation. This is to be expected at or above the flutter speed and illustrates the behavior of the Fourier analysis for a neutrally stable system.

As a further demonstration, the same analysis is performed above the flutter speed at 530 ft/s = 6360 in/s, and large dynamic instabilities are apparent in the plotted results as shown in Figure 9-14. The stable mode again damps out and then the unstable mode diverges very rapidly. These rapidly increasing displacements occur as expected when the wing is disturbed above the flutter velocity. The results presented here demonstrate the consistency of MSC Nastran between solution sequences (that is, SOL 145 calculates

5892 in/s = 491 ft/s as the flutter speed and SOL 146 calculates large dynamic responses at or above this value). However, the transient results here must be regarded as more qualitative than quantitative as far as accuracy of a calculated instability boundary (that is, flutter speed) is concerned.

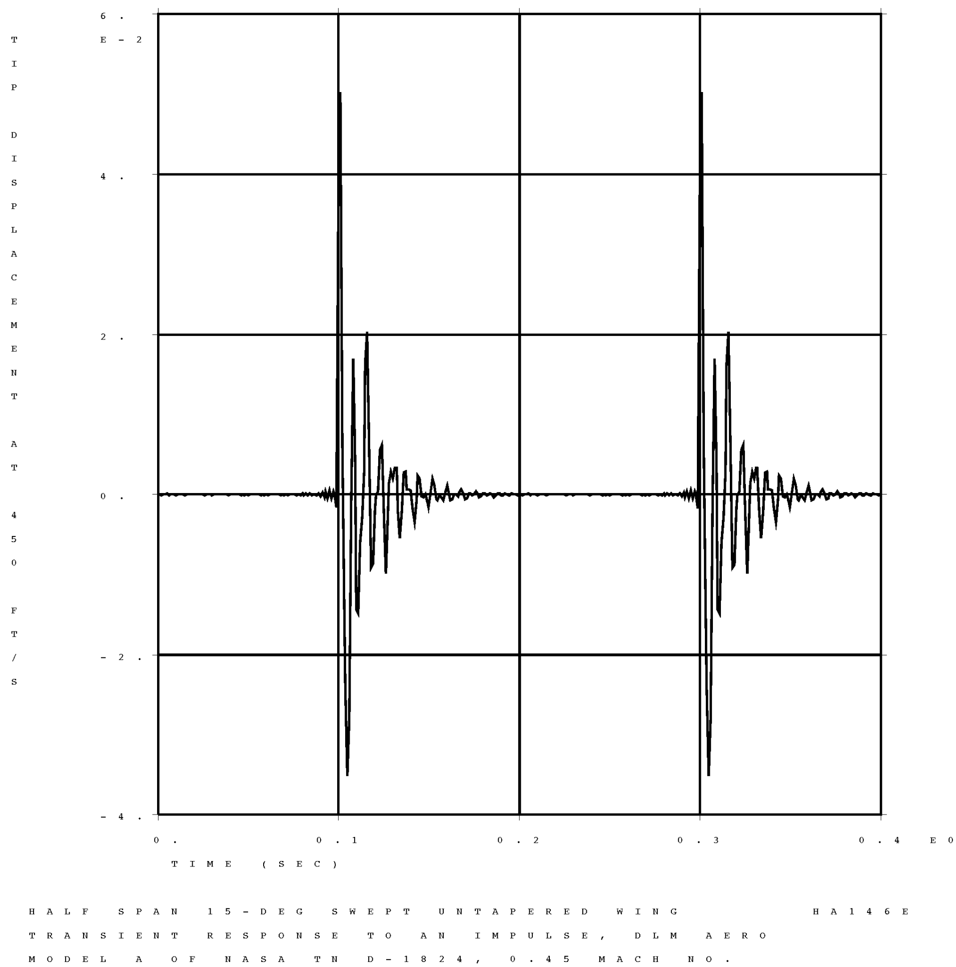


Figure 9-12 Wing Tip Displacement Below Flutter Speed

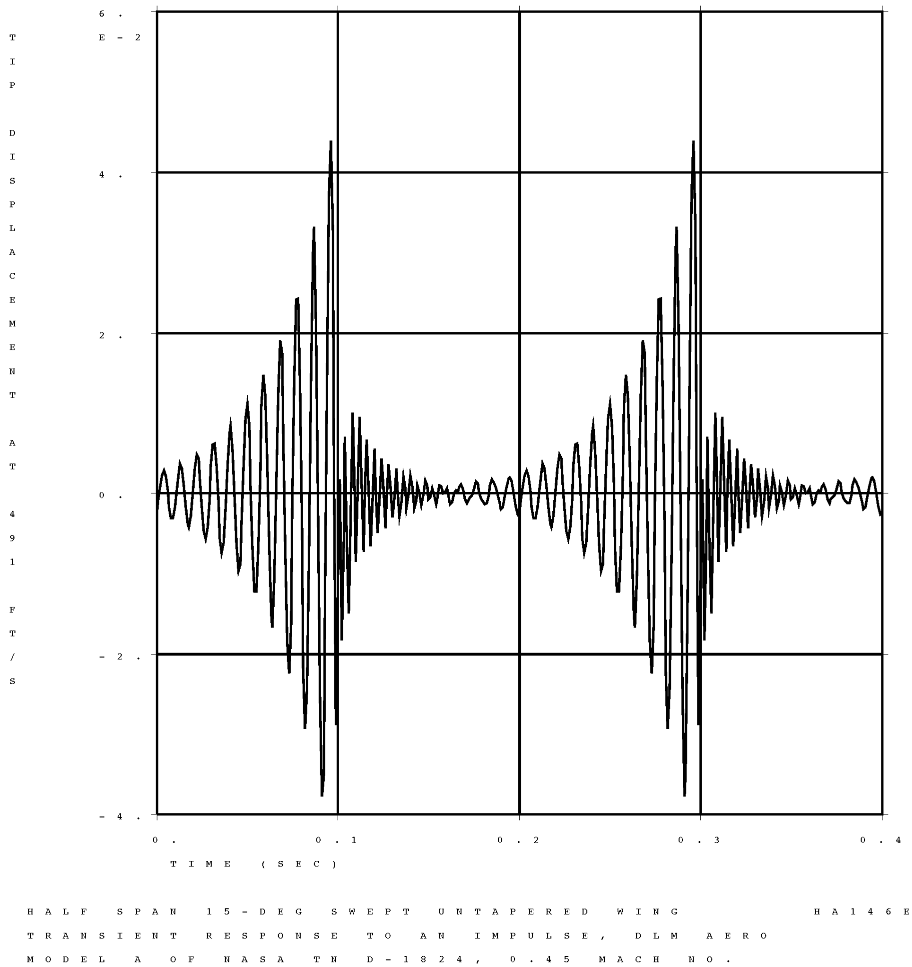


Figure 9-13 Wing Tip Displacement at Flutter Speed

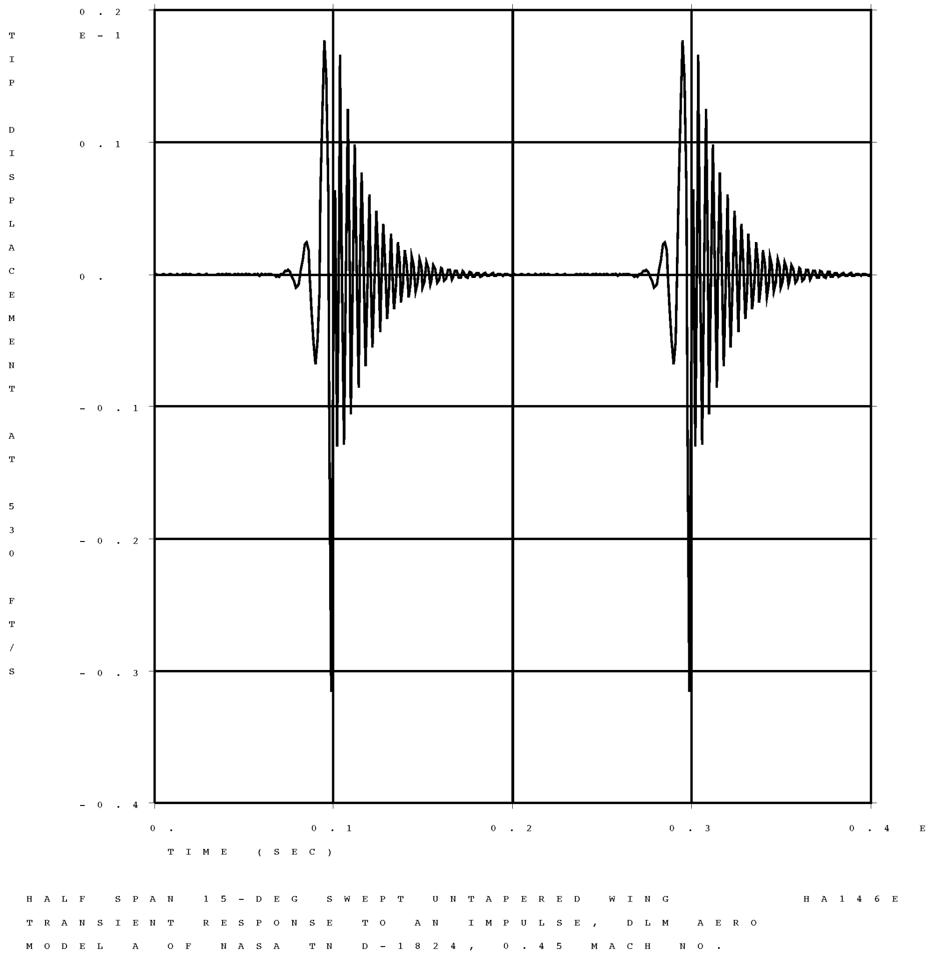


Figure 9-14 Wing Tip Displacement Above Flutter Speed

Listing 9-16 Input Data Files for Response to Impulsive Loading

```
   N A S T R A N    E X E C U T I V E    C O N T R O L    D E C K    E C H O
ID MSC, HA146E
$$$$$$$$ HANDBOOK FOR AEROELASTIC ANALYSIS EXAMPLE HA146E   $$$$$$$$$$$$
$                                                                      $
$       MODEL DESCRIPTION       MODEL A OF NASA TN D-1824              $
$                               HALF SPAN 15 DEGREE SWEPT WING         $
$                               28 QUAD4 PANEL MODEL                   $
$                                                                      $
$       SOLUTION                TRANSIENT RESPONSE TO AN IMPULSE AT    $
$                               THE TIP USING DOUBLET LATTICE AERO     $
$                                                                      $
$       OUTPUT                  PLOT OF TIP DISPLACEMENT TIME          $
$                               HISTORY                                $
$                                                                      $
$$$$$$$$                                                        $$$$$$$$
TIME 10 $ CPU TIME IN MINUTES
SOL 146 $ AEROELASTIC RESPONSE
CEND
```

```
HALF SPAN 15-DEG SWEPT UNTAPERED WING       HA146E                                    PAGE     2
  TRANSIENT RESPONSE TO AN IMPULSE, DLM AERO
 MODEL A OF NASA TN D-1824, 0.45 MACH NO.
                                   C A S E    C O N T R O L    D E C K    E C H O
            CARD
            COUNT
             1      TITLE = HALF SPAN 15-DEG SWEPT UNTAPERED WING       HA146E
             2      SUBTI = TRANSIENT RESPONSE TO AN IMPULSE, DLM AERO
             3      LABEL = MODEL A OF NASA TN D-1824, 0.45 MACH NO.
             4      ECHO  = BOTH
             5        SPC    = 1        $ BOUNDARY CONDITIONS
             6        METHOD = 10       $ MODIFIED GIVENS EIGENVALUE METHOD
             7        SDAMP  = 2000     $ STRUCTURAL DAMPING
             8        DLOAD  = 10       $ LOAD
             9        FREQ   =  101     $ FREQUENCY LIST
            10        TSTEP  =  201     $ SOLUTION TIME STEPS
            11      OUTPUT
            12        SET 1  = 40
            13        DISP = 1   $ DISPLACEMENTS OF POINT 40
            14      OUTPUT(XYOUT)
            15        CSCALE 2.0
            16        PLOTTER = NASTRAN
            17        UPPER TICS = -1
            18        RIGHT TICS = -1
            19        XGRID LINES = YES
            20        YGRID LINES = YES
            21        XTITLE = TIME (SEC)
            22        YTITLE = TIP DISPLACEMENT AT 491 FT/S
            23         XYPLOT DISP / 40(T3)
            24      BEGIN BULK
```

Listing 9-16 Input Data Files for Response to Impulsive Loading (Continued)

```
HALF SPAN 15-DEG SWEPT UNTAPERED WING       HA146E                                                  PAGE     3
  TRANSIENT RESPONSE TO AN IMPULSE, DLM AERO
 MODEL A OF NASA TN D-1824, 0.45 MACH NO.
                                            I N P U T   B U L K   D A T A   D E C K   E C H O

                          .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                          $*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
                          $                                                                         $
                          $        THE ANNOTATIONS IN THIS INPUT DECK ARE INTENDED TO               $
                          $        EXPLAIN THE DATA ON THE CARD IMAGES FOR THIS                     $
                          $        EXAMPLE WITHOUT REFERENCE TO THE VARIOUS MANUALS WHERE           $
                          $        MORE GENERAL DESCRIPTIONS WILL BE FOUND.                         $
                          $                                                                         $
                          $*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
                          INCLUDE PLATE_STRUCT.DAT
                          $                                                                         $
                          $                 * * MASS AND INERTIA PROPERTIES * *                     $
                          $                                                                         $
                          $        THE MAT1 ENTRY DEFINES THE MATERIAL PROPERTIES FOR LINEAR,       $
                          $        TEMPERATURE-INDEPENDENT, ISOTROPIC MATERIALS.  IT LISTS          $
                          $        YOUNGS MODULUS, THE SHEAR MODULUS, POISSONS RATIO (NU            $
                          $        DEFAULTS TO .5*E/G-1.0), MASS DENSITY (RHO DEFAULTS TO           $
                          $        ZERO), THERMAL EXPANSION COEFFICIENT (TREF DEFAULTS TO           $
                          $        ZERO) AND STRUCTURAL ELEMENT DAMPING (WHICH IS TWICE THE         $
                          $        CRITICAL DAMPING RATIO AND DEFAULTS TO ZERO).                    $
                          $                                                                         $
                          $       MID     E       G       NU      RHO     A       TREF    GE
                          MAT1    1       9.2418+63.4993+6        0.097464
                          $                                                                         $
                          $        THE TABDMP1 ENTRY DEFINES DAMPING COEFFICIENTS VS. FREQUENCY.    $
                          $        VALUES ARE LINEARLY INTERPOLATED AND EXTRAPOLATED.               $
                          $                                                                         $
                          $       ID      TYPE
                          TABDMP1 2000                                                              +T2000
                          $       F1      G1      F2      G2      "ENDT"
                          +T2000  0.0     0.01    1000.0  0.01    ENDT
                          $                                                                         $
                          $                    * * STRUCTURAL CONSTRAINTS * *                       $
                          $                                                                         $
                          $        THE SPC1 ENTRY DEFINES SETS OF SINGLE-POINT CONSTRAINTS.         $
                          $        IT LISTS THE DOF COMPONENTS TO BE CONSTRAINED AND THE GRID       $
                          $        POINT NO.                                                        $
                          $                                                                         $
                          $       SID     C       G1      G2      ETC.
                          SPC1    1       6       1       THRU    40
                          SPC1    1       12345   9
                          SPC1    1       12345   25
                          $                                                                         $
                          $        THE ASET1 ENTRY DEFINES DOFS THAT THE USER DESIRES TO BE         $
                          $        INDEPENDENT.  IT LISTS THE DOF COMPONENT NUMBERS AND THE         $
                          $        GRID ID NO.S.  THIS IS THE ALTERNATE FORM THAT USES THE          $
                          $        ALPHANUMERIC THRU OPTION.                                        $
                          $                                                                         $
                          $       C       G               G       ETC.
                          ASET1   3        1      THRU     8
                          ASET1   3       10      THRU    24
                          ASET1   3       26      THRU    40
                          $                                                                         $
                          $                    * * * AERODYNAMIC DATA * * *                         $
                          $                                                                         $
                          $                       * * ELEMENT GEOMETRY * *                          $
                          $                                                                         $
                          $        THE AERO ENTRY SPECIFIES THE AERO COORDINATE SYSTEM, THE         $
                          $        VELOCITY (USED FOR DATA RECOVERY), THE REFERENCE CHORD           $
                          $        AND FLUID DENSITY, PLUS SYMMETRY KEYS.  SYMXZ=1 INDICATES        $
                          $        THAT THE MODEL IS MOUNTED ON A WALL THAT ACTS AS A REFLECTING    $
                          $        PLANE; SYMXY = 0 INDICATES THAT THE MODEL IS MOUNTED FAR         $
                          $        ENOUGH FROM THE FLOOR SO THAT REFLECTION EFFECTS ARE             $
                          $        NEGLIGIBLE.                                                      $
                          $                                                                         $
                          $       ACSID   VELOCITY REFC   RHOREF  SYMXZ   SYMXY
                          AERO    0       5892.   2.0706  1.1092-7+1
                          $                                                                         $
                          $       THE PARAM,Q ENTRY SPECIFIES THE DYNAMIC PRESSURE. (THIS           $
                          $       ENTRY IS REQUIRED IN SOL 146.)                                    $
                          $                                                                         $
                          PARAM   Q       1.925
```

Main Index

Listing 9-16 Input Data Files for Response to Impulsive Loading (Continued)

```
$              * * SPLINE FIT ON THE LIFTING SURFACES * *               $
$                                                                       $
$                  * SURFACE SPLINE FIT ON THE WING *                   $
$
$        THE SPLINE1 ENTRY DEFINES A SURFACE SPLINE FOR INTERPO-        $
$        LATING OUT-OF-PLANE DISPLACEMENTS FROM THE STRUCTURAL          $
$        GRID POINTS ON THE SETG ENTRY TO THE SUB-REGION DEFINED        $
$        BY AERODYNAMIC BOXES 101 THRU 124 OF THE REGION ON THE         $
$        CAERO1 ENTRY.  DZ=0 SPECIFIES THAT NO SMOOTHING OF THE         $
$        SPLINE IS TO BE IMPOSED.                                       $
$                                                                       $
$       EID     CAERO   BOX1    BOX2    SETG    DZ                      $
SPLINE1 100     101     101     124     100     .0
$                                                                       $
$        THE SET1 ENTRY DEFINES THE SET OF POINTS TO BE USED BY         $
$        THE SURFACE SPLINE FOR INTERPOLATION.                          $
$                                                                       $
$       SID     G1      G2      G3      G4      ETC
SET1    100     2       4       6       8       9       11      13      +S1
+S1     15      18      20      22      24      25      27      29      +S2
+S2     31      34      36      38      40
$                                                                       $
$        THE CAERO1 ENTRY IS USED FOR DOUBLET LATTICE AERODYNAMICS.     $
$        LISTED ARE ITS PAERO ENTRY ID AND THE COORDINATE SYSTEM        $
$        FOR LOCATING THE INBOARD AND OUTBOARD LEADING EDGE POINTS      $
$        (1 AND 4).  NSPAN AND NCHORD, OR LSPAN AND LCHORD, ARE         $
$        USED TO PARTITION THE WING INTO AERODYNAMIC PANELS.            $
$        THE FORMER FOR UNIFORMLY SPACED PANELS AND THE LATTER          $
$        FOR NON-UNIFORM SPACING.  IGID IS THE ID OF ITS ASSOCIATED     $
$        INTERFERENCE GROUP.  THE CONTINUATION ENTRY DEFINES POINTS     $
$        1 AND 4, THE ROOT CHORD AND TIP CHORD.  THE BOXES FORMED       $
$        BY THE GRID LINES WILL BE NUMBERED BEGINNING WITH EID          $
$        SO CHOOSE A NUMBER THAT IS UNIQUE, AND IS GREATER THAN ALL     $
$        STRUCTURAL GRID, SCALAR AND EXTRA POINT IDS.                   $
$                                                                       $
$       EID     PID     CP      NSPAN   NCHORD  LSPAN   LCHORD  IGID
CAERO1  101     1       0       6       4                       1       +CA101
$      ( FWD LEFT POINT  )   ROOTCHORD ( FWD RIGHT POINT  )  TIP CHORD
$       X1      Y1      Z1      X12     X4      Y4      Z4      X14
+CA101  .0      .0      .0      2.07055 1.48044 5.52510 0.0     2.07055
$                                                                       $
$        THE PAERO1 ENTRY IS REQUIRED EVEN THOUGH IT IS NON-FUNCTIONAL  $
$        (BECAUSE THERE ARE NO ASSOCIATED BODIES IN THIS EXAMPLE).      $
$                                                                       $
$       PID     B1      B2      B3      B4      B5      B6
PAERO1  1
$                                                                       $
$                                                                       $
$                 * * * TRANSIENT RESPONSE SOLUTION  * * *              $
$                                                                       $
$                      * * AERODYNAMIC CONDITIONS * *                   $
$                                                                       $
$        ALL COMBINATIONS OF MACH NUMBER AND REDUCED FREQUENCY LISTED   $
$        ON THE MKAERO1 ENTRY AND ITS CONTINUATION ENTRY WILL BE USED   $
$        TO GENERATE GENERALIZED AERO FORCE MATRICES.  IF MORE THAN     $
$        EIGHT MACH NO.S OR REDUCED FREQUENCIES ARE REQUIRED A SECOND   $
$        MKAERO1 ENTRY IS NECESSARY.                                    $
$                                                                       $
$       M1      M2      M3      M4
MKAERO1 .45                                                             +MK
+MK     .001    .10     .12     .14     .16     .20
$                                                                       $
$                   * * EIGENSOLUTION AND LOAD DATA * *                 $
$                                                                       $
$        THE EIGR ENTRY DEFINES THE METHOD OF EXTRACTING THE EIGEN-     $
$        VALUES OF THE STRUCTURE. IN THIS CASE THE GIVENS METHOD.       $
$        SIX MODES ARE DESIRED, NORMALIZED ON THE MAXIMUM DISPLACEMENTS.$
$                                                                       $
$       SID     METHOD  F1      F2      NE      ND
EIGR    10      GIV     .0      4000.   12      12                      +ER
$       NORM
+ER     MAX
$                                                                       $
```

Listing 9-16 Input Data Files for Response to Impulsive Loading (Continued)

```
$        THE TLOAD1 ENTRY DEFINES A TIME DEPENDENT DYNAMIC LOAD OR AN   $
$        ENFORCED MOTION.  LISTED ARE THE IDS OF A DAREA ENTRY, A DELAY $
$        ENTRY, THE TYPE OF DYNAMIC EXCITATION AND THE TABLED ID.       $
$                                                                       $
$       SID     DAREA   DELAY   TYPE    TID
TLOAD1  10      12      13              14
$
$        THE DAREA ENTRY DEFINES THE POINT WHERE THE DYNAMIC LOAD IS    $
$        TO BE APPLIED (IN THIS CASE THE CENTER OF THE SECOND FWDMOST   $
$        AERODYNAMIC BOX), THE DOF COMPONENT AND THE ASSOCIATED AREA    $
$        SCALE FACTOR.                                                  $
$                                                                       $
$       SID     P       C       A
DAREA   12      24      3       1.0
$                                                                       $
$        THE DELAY ENTRY SPECIFIES THE GRID POINT, DISPLACEMENT         $
$        COMPONENT AND THE TIME DELAY OF ONSET OF THE FORCING           $
$        FUNCTION.                                                      $
$                                                                       $
$       SID     P       C       T
DELAY   13      24      3       .1
$                                                                       $
$        THE TABLED1 ENTRY DEFINES A TABULAR FUNCTION FOR USE IN        $
$        GENERATING FREQUENCY AND TIME DEPENDENT LOADS.  IN THIS        $
$        CASE THE PULSE TO BE APPLIED TO THE WING TIP.                  $
$                                                                       $
$       SID
TABLED1 14                                                              +T14
$       X1      Y1      X2      Y2      ETC
+T14    0.0     1.+6    1.-6    1.+6    1.-6    -1.+6   2.-6    -1.+6   +T15
+T15    ENDT
$                                                                       $
$        THE FREQ1 ENTRY DEFINES THE SET OF FREQUENCIES USED TO OBTAIN  $
$        THE FREQUENCY RESPONSE SOLUTION.  LISTED ARE THE STARTING      $
$        FREQUENCY, FREQUENCY INCREMENT AND NUMBER OF INCREMENTS.       $
$                                                                       $
$        THE PERIOD OF REPETITION OF THE FORCE IS 1/DF.                 $
$                                                                       $
$       SID     F1      DF      NDF
FREQ1   101     0.0     5.0     90
$                                                                       $
$        THE TSTEP ENTRY DEFINES THE TIME STEP INTERVALS AT WHICH THE   $
$        TRANSIENT RESPONSES ARE DESIRED.  LISTED ARE THE NUMBER OF     $
$        STEPS, THE TIME INTERVAL AND NO THE INTERVALS FOR OUTPUT.      $
$                                                                       $
$       SID     N       DT      NO
TSTEP   201     400     .001    1
$                                                                       $
$                       * * PARAMETERS * *                              $
$                                                                       $
$        PARAM GRDPNT CAUSES THE INERTIAL MATRIX TO BE PRINTED WITH     $
$        RESPECT TO COORDINATES THROUGH THE GRID POINT SPECIFIED.       $
$
PARAM   GRDPNT  17
$
$        THE PARAMETER KDAMP DETERMINES THE MANNER OF INCLUDING         $
$        STRUCTURAL DAMPING IN THE EQUATIONS OF MOTION (SEE THE         $
$        HANDBOOK FOR DYNAMIC ANALYSIS, SECTION 3.2.2).  IF SET TO      $
$        -1, MODAL STRUCTURAL DAMPING IS INCLUDED AS THE IMAGINARY      $
$        PART OF A COMPLEX STIFFNESS MATRIX.                            $
$
PARAM   KDAMP   -1
$                                                                       $
$        THE PARAM,LMODES,N ENTRY SPECIFIES THAT N VIBRATION MODES      $
$        ARE TO BE USED IN THE ANALYSIS.                                $
$
PARAM   LMODES  4
$
ENDDATA
INPUT BULK DATA CARD COUNT =     342
```

Listing 9-17 Sorted Bulk Data for Response to Impulsive Loading

```
HALF SPAN 15-DEG SWEPT UNTAPERED WING       HA146E                                                        PAGE    10
 TRANSIENT RESPONSE TO AN IMPULSE, DLM AERO
 MODEL A OF NASA TN D-1824, 0.45 MACH NO.
                                            S O R T E D   B U L K   D A T A   E C H O
           CARD
           COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
              1-        AERO    0       5892.   2.0706  1.1092-7+1
              2-        ASET1   3       1       THRU    8
              3-        ASET1   3       10      THRU    24
              4-        ASET1   3       26      THRU    40
              5-        CAERO1  101     1       0       6       4                       1       +CA101
              6-        +CA101  .0      .0      .0      2.07055 1.48044 5.52510 0.0     2.07055
              7-        CQUAD4  1       1       1       2       10      9                       +M00000
              8-        +M00000                 0.0     0.0     .041    .041
              9-        CQUAD4  2       1       2       3       11      10                      +M00001
             10-        +M00001                 0.0     0.0     .041    .041
             11-        CQUAD4  3       1       3       4       12      11                      +M00002
             12-        +M00002                 0.0     0.0     .041    .041
             13-        CQUAD4  4       1       4       5       13      12                      +M00003
             14-        +M00003                 0.0     0.0     .041    .041
             15-        CQUAD4  5       1       5       6       14      13                      +M00004
             16-        +M00004                 0.0     0.0     .041    .041
             17-        CQUAD4  6       1       6       7       15      14                      +M00005
             18-        +M00005                 0.0     0.0     .041    .041
             19-        CQUAD4  7       1       7       8       16      15                      +M00006
             20-        +M00006                 0.0     0.0     .041    .041
             21-        CQUAD4  8       1       9       10      18      17
             22-        CQUAD4  9       1       10      11      19      18
             23-        CQUAD4  10      1       11      12      20      19
             24-        CQUAD4  11      1       12      13      21      20
             25-        CQUAD4  12      1       13      14      22      21
             26-        CQUAD4  13      1       14      15      23      22
             27-        CQUAD4  14      1       15      16      24      23
             28-        CQUAD4  15      1       17      18      26      25
             29-        CQUAD4  16      1       18      19      27      26
             30-        CQUAD4  17      1       19      20      28      27
             31-        CQUAD4  18      1       20      21      29      28
             32-        CQUAD4  19      1       21      22      30      29
             33-        CQUAD4  20      1       22      23      31      30
             34-        CQUAD4  21      1       23      24      32      31
             35-        CQUAD4  22      1       25      26      34      33                      +M00007
             36-        +M00007                 .041    .041    0.0     0.0
             37-        CQUAD4  23      1       26      27      35      34                      +M00008
             38-        +M00008                 .041    .041    0.0     0.0
             39-        CQUAD4  24      1       27      28      36      35                      +M00009
             40-        +M00009                 .041    .041    0.0     0.0
             41-        CQUAD4  25      1       28      29      37      36                      +M00010
             42-        +M00010                 .041    .041    0.0     0.0
             43-        CQUAD4  26      1       29      30      38      37                      +M00011
             44-        +M00011                 .041    .041    0.0     0.0
             45-        CQUAD4  27      1       30      31      39      38                      +M00012
             46-        +M00012                 .041    .041    0.0     0.0
             47-        CQUAD4  28      1       31      32      40      39                      +M00013
             48-        +M00013                 .041    .041    0.0     0.0
             49-        DAREA   12      24      3       1.0
             50-        DELAY   13      24      3       .1
             51-        EIGR    10      GIV     .0      4000.   12      12                      +ER
             52-        +ER     MAX
             53-        FREQ1   101     0.0     5.0     90
             54-        GRID    1               0.0     0.0     0.0
             55-        GRID    2               .211491 .7893   0.0
             56-        GRID    3               .422983 1.5786  0.0
             57-        GRID    4               .634474 2.3679  0.0
             58-        GRID    5               .845966 3.1572  0.0
             59-        GRID    6               1.05746 3.9465  0.0
```

Listing 9-17 Sorted Bulk Data for Response to Impulsive Loading (Continued)

```
  60-        GRID    7               1.26895 4.7358  0.0
  61-        GRID    8               1.48044 5.5251  0.0
  62-        GRID    9               .258819 0.0     0.0
  63-        GRID    10              .47031  .7893   0.0
  64-        GRID    11              .681802 1.5786  0.0
  65-        GRID    12              .893293 2.3679  0.0
  66-        GRID    13              1.10478 3.1572  0.0
  67-        GRID    14              1.31628 3.9465  0.0
  68-        GRID    15              1.52777 4.7358  0.0
  69-        GRID    16              1.73926 5.5251  0.0
  70-        GRID    17              1.03528 0.0     0.0
  71-        GRID    18              1.24677 .7893   0.0
  72-        GRID    19              1.45826 1.5786  0.0
  73-        GRID    20              1.66975 2.3679  0.0
  74-        GRID    21              1.88124 3.1572  0.0
  75-        GRID    22              2.09273 3.9465  0.0
  76-        GRID    23              2.30422 4.7358  0.0
  77-        GRID    24              2.51572 5.5251  0.0
  78-        GRID    25              1.81173 0.0     0.0
  79-        GRID    26              2.02322 .7893   0.0
  80-        GRID    27              2.23471 1.5786  0.0
  81-        GRID    28              2.44621 2.3679  0.0
  82-        GRID    29              2.6577  3.1572  0.0
  83-        GRID    30              2.86919 3.9465  0.0
  84-        GRID    31              3.08068 4.7358  0.0
  85-        GRID    32              3.29217 5.5251  0.0
  86-        GRID    33              2.07055 0.0     0.0
  87-        GRID    34              2.28204 .7893   0.0
  88-        GRID    35              2.49353 1.5786  0.0
  89-        GRID    36              2.70502 2.3679  0.0
  90-        GRID    37              2.91652 3.1572  0.0
  91-        GRID    38              3.12801 3.9465  0.0
  92-        GRID    39              3.3395  4.7358  0.0
  93-        GRID    40              3.55099 5.5251  0.0
  94-        MAT1    1       9.2418+63.4993+6        0.097464
  95-        MKAERO1 .45                                                     +MK
  96-        +MK     .001    .10     .12     .14     .16     .20
  97-        PAERO1  1
  98-        PARAM   COUPMASS1
  99-        PARAM   GRDPNT  17
 100-        PARAM   KDAMP   -1
 101-        PARAM   LMODES  4
 102-        PARAM   Q       1.925
 103-        PARAM   WTMASS  .0025901
 104-        PSHELL  1       1       .041    1               1
 105-        SET1    100     2       4       6       8       9       11      13      +S1
 106-        +S1     15      18      20      22      24      25      27      29      +S2
 107-        +S2     31      34      36      38      40
 108-        SPC1    1       6       1       THRU    40
 109-        SPC1    1       12345   9
 110-        SPC1    1       12345   25
 111-        SPLINE1 100     101     101     124     100     .0
 112-        TABDMP1 2000                                                    +T2000
 113-        +T2000  0.0     0.01    1000.0  0.01    ENDT
 114-        TABLED1 14                                                      +T14
 115-        +T14    0.0     1.+6    1.-6    1.+6    1.-6    -1.+6   2.-6    -1.+6   +T15
 116-        +T15    ENDT
 117-        TLOAD1  10      12      13              14
 118-        TSTEP   201     400     .001    1
             ENDDATA
       TOTAL COUNT=      119
```

Listing 9-18 Output for Response to Impulsive Loading

```
 HALF SPAN 15-DEG SWEPT UNTAPERED WING       HA146E                                                      PAGE    19
   TRANSIENT RESPONSE TO AN IMPULSE, DLM AERO
   MODEL A OF NASA TN D-1824, 0.45 MACH NO.
    POINT-ID =       40
                                            D I S P L A C E M E N T   V E C T O R

     TIME        TYPE          T1              T2              T3              R1              R2              R3
 0.0              G      0.0             0.0            -2.161281E-03  -2.694785E-04   7.338977E-04   0.0
 1.000000E-03     G      0.0             0.0            -9.106084E-04  -1.683799E-05   4.789137E-04   0.0
 2.000000E-03     G      0.0             0.0             7.477202E-04   4.718859E-05  -1.609862E-04   0.0
 3.000000E-03     G      0.0             0.0             2.277885E-03   3.077695E-04  -5.837492E-04   0.0
 4.000000E-03     G      0.0             0.0             2.869780E-03   5.649505E-04  -8.780780E-04   0.0
 5.000000E-03     G      0.0             0.0             2.179967E-03   5.142913E-04  -6.107069E-04   0.0
 6.000001E-03     G      0.0             0.0             2.591812E-04  -6.447673E-05  -3.324048E-04   0.0
 7.000001E-03     G      0.0             0.0            -1.724737E-03  -3.929759E-04   3.741779E-04   0.0
 8.000000E-03     G      0.0             0.0            -3.069244E-03  -5.150136E-04   8.119160E-04   0.0
 9.000001E-03     G      0.0             0.0            -3.035107E-03  -4.234802E-04   1.019383E-03   0.0
 1.000000E-02     G      0.0             0.0            -1.733900E-03  -3.576560E-04   6.237020E-04   0.0
 1.100000E-02     G      0.0             0.0             5.516880E-04   3.496103E-05  -3.031057E-05   0.0
 1.200000E-02     G      0.0             0.0             2.762273E-03   5.524010E-04  -6.235335E-04   0.0
 1.300000E-02     G      0.0             0.0             3.771174E-03   7.348959E-04  -1.094617E-03   0.0
 1.400000E-02     G      0.0             0.0             3.087068E-03   5.182477E-04  -9.667448E-04   0.0
 1.500000E-02     G      0.0             0.0             8.955137E-04   4.657419E-05  -5.671644E-04   0.0
 1.600000E-02     G      0.0             0.0            -1.699995E-03  -2.580434E-04   3.869796E-04   0.0
 1.700000E-02     G      0.0             0.0            -3.811964E-03  -6.524998E-04   9.692166E-04   0.0
 1.800000E-02     G      0.0             0.0            -4.218616E-03  -7.479618E-04   1.320688E-03   0.0
 1.900000E-02     G      0.0             0.0            -2.774433E-03  -5.563300E-04   9.165197E-04   0.0
 2.000000E-02     G      0.0             0.0             1.785848E-04   9.601130E-05   2.230951E-04   0.0
 2.100000E-02     G      0.0             0.0             3.135004E-03   6.180879E-04  -6.944844E-04   0.0
 2.200000E-02     G      0.0             0.0             4.823445E-03   8.400311E-04  -1.381263E-03   0.0
 2.300000E-02     G      0.0             0.0             4.398568E-03   7.317043E-04  -1.382091E-03   0.0
 2.400000E-02     G      0.0             0.0             1.915079E-03   3.196245E-04  -8.582898E-04   0.0
 2.500000E-02     G      0.0             0.0            -1.566270E-03  -2.366602E-04   2.799646E-04   0.0
 2.600000E-02     G      0.0             0.0            -4.656748E-03  -8.871090E-04   1.104175E-03   0.0
 2.700000E-02     G      0.0             0.0            -5.652717E-03  -1.011126E-03   1.723195E-03   0.0
 2.800000E-02     G      0.0             0.0            -4.183356E-03  -7.404945E-04   1.361757E-03   0.0
 2.900000E-02     G      0.0             0.0            -5.792427E-04  -1.157179E-05   5.545950E-04   0.0
 3.000000E-02     G      0.0             0.0             3.378134E-03   5.921518E-04  -7.465787E-04   0.0
 3.100000E-02     G      0.0             0.0             6.118540E-03   1.079806E-03  -1.669955E-03   0.0
 3.200000E-02     G      0.0             0.0             6.154180E-03   1.087455E-03  -1.892105E-03   0.0
 3.300000E-02     G      0.0             0.0             3.357990E-03   5.938875E-04  -1.300285E-03   0.0
 3.400000E-02     G      0.0             0.0            -1.177767E-03  -2.379042E-04   3.240915E-05   0.0
 3.500000E-02     G      0.0             0.0            -5.483943E-03  -1.046055E-03   1.253511E-03   0.0
 3.599999E-02     G      0.0             0.0            -7.413968E-03  -1.284480E-03   2.216528E-03   0.0
 3.699999E-02     G      0.0             0.0            -6.145379E-03  -1.079321E-03   1.945101E-03   0.0
 3.799999E-02     G      0.0             0.0            -1.841564E-03  -2.627536E-04   1.013358E-03   0.0
 3.899999E-02     G      0.0             0.0             3.452360E-03   5.953839E-04  -6.958374E-04   0.0
 3.999999E-02     G      0.0             0.0             7.620675E-03   1.405553E-03  -1.962146E-03   0.0
 4.099999E-02     G      0.0             0.0             8.392774E-03   1.481208E-03  -2.554084E-03   0.0
 4.199998E-02     G      0.0             0.0             5.400310E-03   9.343401E-04  -1.930600E-03   0.0
 4.299998E-02     G      0.0             0.0            -3.281469E-04  -1.217144E-05  -3.676712E-04   0.0
 4.399998E-02     G      0.0             0.0            -6.228817E-03  -1.147661E-03   1.381334E-03   0.0
 4.499998E-02     G      0.0             0.0            -9.583375E-03  -1.677181E-03   2.766101E-03   0.0
 4.599998E-02     G      0.0             0.0            -8.786102E-03  -1.569629E-03   2.709862E-03   0.0
 4.699998E-02     G      0.0             0.0            -3.758803E-03  -6.020886E-04   1.679330E-03   0.0
 4.799997E-02     G      0.0             0.0             3.195483E-03   5.808923E-04  -4.909628E-04   0.0
 4.899997E-02     G      0.0             0.0             9.246888E-03   1.725094E-03  -2.266037E-03   0.0
 4.999997E-02     G      0.0             0.0             1.122023E-02   1.952351E-03  -3.378977E-03   0.0
 5.099997E-02     G      0.0             0.0             8.268386E-03   1.448823E-03  -2.779186E-03   0.0
 5.199997E-02     G      0.0             0.0             1.187526E-03   1.346227E-04  -9.860625E-04   0.0
 5.299997E-02     G      0.0             0.0            -6.789724E-03  -1.237243E-03   1.418749E-03   0.0
 5.399996E-02     G      0.0             0.0            -1.216828E-02  -2.180339E-03   3.363178E-03   0.0
 5.499996E-02     G      0.0             0.0            -1.223997E-02  -2.178860E-03   3.716934E-03   0.0
 5.599996E-02     G      0.0             0.0            -6.585141E-03  -1.086310E-03   2.616484E-03   0.0
 5.699996E-02     G      0.0             0.0             2.365747E-03   4.580293E-04  -7.443000E-05   0.0
 5.799996E-02     G      0.0             0.0             1.090876E-02   2.028860E-03  -2.546651E-03   0.0
 5.899996E-02     G      0.0             0.0             1.475121E-02   2.570582E-03  -4.359502E-03   0.0
 5.999995E-02     G      0.0             0.0             1.219421E-02   2.171182E-03  -3.910340E-03   0.0
 6.099995E-02     G      0.0             0.0             3.637522E-03   5.390851E-04  -1.920502E-03   0.0
 6.199995E-02     G      0.0             0.0            -6.959493E-03  -1.275191E-03   1.295697E-03   0.0
 6.299995E-02     G      0.0             0.0            -1.512759E-02  -2.751445E-03   3.995620E-03   0.0
 6.399995E-02     G      0.0             0.0            -1.668699E-02  -2.942015E-03   5.009026E-03   0.0
 6.499995E-02     G      0.0             0.0            -1.065213E-02  -1.810854E-03   3.894011E-03   0.0
 6.599995E-02     G      0.0             0.0             6.605326E-04   1.788970E-04   6.545364E-04   0.0
 6.699996E-02     G      0.0             0.0             1.245513E-02   2.318320E-03  -2.736080E-03   0.0
 6.799996E-02     G      0.0             0.0             1.905753E-02   3.352417E-03  -5.492608E-03   0.0
 6.899996E-02     G      0.0             0.0             1.744230E-02   3.119644E-03  -5.404990E-03   0.0
 6.999996E-02     G      0.0             0.0             7.401054E-03   1.161095E-03  -3.280462E-03   0.0
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Listing 9-18 Output for Response to Impulsive Loading (Continued)

```
7.099997E-02    G    0.0         0.0         -6.423918E-03  -1.182372E-03   9.227177E-04   0.0
7.199997E-02    G    0.0         0.0         -1.837942E-02  -3.379039E-03   4.615306E-03   0.0
7.299997E-02    G    0.0         0.0         -2.232142E-02  -3.914595E-03   6.620240E-03   0.0
7.399997E-02    G    0.0         0.0         -1.635319E-02  -2.851486E-03   5.606498E-03   0.0
7.499997E-02    G    0.0         0.0         -2.322271E-03  -3.011227E-04   1.838494E-03   0.0
7.599998E-02    G    0.0         0.0          1.361746E-02   2.541407E-03  -2.745595E-03   0.0
7.699998E-02    G    0.0         0.0          2.416926E-02   4.292897E-03  -6.765408E-03   0.0
7.799998E-02    G    0.0         0.0          2.433109E-02   4.346912E-03  -7.340173E-03   0.0
7.899998E-02    G    0.0         0.0          1.297798E-02   2.109395E-03  -5.202504E-03   0.0
7.999998E-02    G    0.0         0.0         -4.747977E-03  -8.806175E-04   1.717783E-04   0.0
8.099999E-02    G    0.0         0.0         -2.176206E-02  -4.057572E-03   5.125439E-03   0.0
8.199999E-02    G    0.0         0.0         -2.930862E-02  -5.118982E-03   8.594584E-03   0.0
8.299999E-02    G    0.0         0.0         -2.417410E-02  -4.297417E-03   7.860237E-03   0.0
8.399999E-02    G    0.0         0.0         -7.120336E-03  -1.057499E-03   3.665489E-03   0.0
8.499999E-02    G    0.0         0.0          1.396027E-02   2.589105E-03  -2.454116E-03   0.0
8.600000E-02    G    0.0         0.0          3.008194E-02   5.414958E-03  -8.133010E-03   0.0
8.700000E-02    G    0.0         0.0          3.320365E-02   5.909556E-03  -9.779229E-03   0.0
8.800000E-02    G    0.0         0.0          2.100571E-02   3.507315E-03  -7.889461E-03   0.0
8.900000E-02    G    0.0         0.0         -1.331253E-03  -2.684275E-04  -1.094840E-03   0.0
9.000000E-02    G    0.0         0.0         -2.500815E-02  -4.769898E-03   5.329790E-03   0.0
9.100001E-02    G    0.0         0.0         -3.772551E-02  -6.508180E-03   1.104246E-02   0.0
9.200001E-02    G    0.0         0.0         -3.482014E-02  -6.369294E-03   1.069613E-02   0.0
9.300001E-02    G    0.0         0.0         -1.426806E-02  -2.054690E-03   6.447099E-03   0.0
9.400001E-02    G    0.0         0.0          1.261736E-02   2.120463E-03  -1.718998E-03   0.0
9.500001E-02    G    0.0         0.0          3.706274E-02   7.019433E-03  -9.542762E-03   0.0
9.600002E-02    G    0.0         0.0          4.398673E-02   7.507279E-03  -1.259332E-02   0.0
9.700002E-02    G    0.0         0.0          3.280523E-02   5.891309E-03  -1.202114E-02   0.0
9.800002E-02    G    0.0         0.0          4.400965E-03   5.422819E-04  -2.173394E-03   0.0
9.900002E-02    G    0.0         0.0         -2.875855E-02  -6.113509E-03   3.276326E-03   0.0
1.000000E-01    G    0.0         0.0         -1.084636E-02   1.394668E-02   1.216558E-02   0.0
1.010000E-01    G    0.0         0.0          1.761314E-03   6.758023E-04   6.118340E-03   0.0
1.020000E-01    G    0.0         0.0         -1.835013E-02  -3.249122E-02  -9.178097E-03   0.0
1.030000E-01    G    0.0         0.0         -5.624933E-03  -6.676541E-04   1.752827E-03   0.0
1.040000E-01    G    0.0         0.0          7.094903E-03   2.770534E-02   9.704382E-03   0.0
1.050000E-01    G    0.0         0.0         -5.870812E-03  -9.856158E-04   1.912805E-03   0.0
1.060000E-01    G    0.0         0.0         -1.496366E-02  -2.624631E-02  -7.775354E-03   0.0
1.070000E-01    G    0.0         0.0         -2.143780E-03  -1.292189E-03  -1.487887E-03   0.0
1.080000E-01    G    0.0         0.0          1.007576E-02   2.327809E-02   7.344068E-03   0.0
1.090000E-01    G    0.0         0.0          2.140879E-05   7.774846E-04   5.114150E-04   0.0
1.100000E-01    G    0.0         0.0         -8.525770E-03  -2.054968E-02  -6.365588E-03   0.0
1.110000E-01    G    0.0         0.0          5.925606E-04  -1.301968E-03  -1.781846E-03   0.0
1.120000E-01    G    0.0         0.0          9.585598E-03   1.909244E-02   5.963188E-03   0.0
1.130001E-01    G    0.0         0.0          9.453899E-04   1.525876E-03   8.461776E-04   0.0
1.140001E-01    G    0.0         0.0         -7.286575E-03  -1.674620E-02  -5.079691E-03   0.0
1.150001E-01    G    0.0         0.0         -4.427186E-04  -1.687805E-03  -1.169393E-03   0.0
1.160001E-01    G    0.0         0.0          6.698325E-03   1.513168E-02   4.759808E-03   0.0
1.170001E-01    G    0.0         0.0          3.228778E-04   1.783952E-03   1.309534E-03   0.0
1.180001E-01    G    0.0         0.0         -6.492403E-03  -1.373243E-02  -4.258779E-03   0.0
1.190001E-01    G    0.0         0.0         -5.793792E-04  -1.783126E-03  -8.945310E-04   0.0
1.200001E-01    G    0.0         0.0          5.595589E-03   1.215926E-02   3.525509E-03   0.0
1.210001E-01    G    0.0         0.0          9.382306E-04   2.036112E-03   1.181423E-03   0.0
1.220001E-01    G    0.0         0.0         -4.914370E-03  -1.104605E-02  -3.611268E-03   0.0
1.230001E-01    G    0.0         0.0         -5.407608E-04  -1.827426E-03  -8.969129E-04   0.0
1.240001E-01    G    0.0         0.0          4.353250E-03   9.775946E-03   2.912787E-03   0.0
1.250001E-01    G    0.0         0.0          4.958602E-04   1.906641E-03   1.088643E-03   0.0
1.260001E-01    G    0.0         0.0         -4.313920E-03  -8.901853E-03  -2.624643E-03   0.0
1.270001E-01    G    0.0         0.0         -8.775310E-04  -1.918951E-03  -8.893022E-04   0.0
1.280001E-01    G    0.0         0.0          3.668032E-03   7.957551E-03   2.494216E-03   0.0
1.290001E-01    G    0.0         0.0          8.545416E-04   1.833476E-03   7.230282E-04   0.0
1.300001E-01    G    0.0         0.0         -2.885876E-03  -6.988012E-03  -2.110646E-03   0.0
1.310001E-01    G    0.0         0.0         -4.598846E-04  -1.805835E-03  -1.050309E-03   0.0
1.320001E-01    G    0.0         0.0          3.107847E-03   6.451221E-03   1.999515E-03   0.0
1.330001E-01    G    0.0         0.0          5.193101E-04   1.648978E-03   6.741227E-04   0.0
1.340001E-01    G    0.0         0.0         -2.859755E-03  -5.697040E-03  -1.548297E-03   0.0
1.350001E-01    G    0.0         0.0         -1.054114E-03  -1.768444E-03  -6.878451E-04   0.0
1.360001E-01    G    0.0         0.0          2.091984E-03   5.076477E-03   1.651074E-03   0.0
1.370001E-01    G    0.0         0.0          5.825646E-04   1.579826E-03   7.299435E-04   0.0
1.380001E-01    G    0.0         0.0         -1.893196E-03  -4.532992E-03  -1.450750E-03   0.0
1.390001E-01    G    0.0         0.0         -1.927833E-04  -1.422811E-03  -6.832129E-04   0.0
1.400001E-01    G    0.0         0.0          2.239970E-03   4.111860E-03   1.006444E-03   0.0
1.410001E-01    G    0.0         0.0          8.484185E-04   1.528408E-03   6.216000E-04   0.0
1.420001E-01    G    0.0         0.0         -1.795201E-03  -3.713425E-03  -1.192890E-03   0.0
1.430001E-01    G    0.0         0.0         -8.529953E-04  -1.378325E-03  -3.824753E-04   0.0
1.440001E-01    G    0.0         0.0          9.825776E-04   3.126876E-03   1.021087E-03   0.0
1.450001E-01    G    0.0         0.0          1.680465E-04   1.261815E-03   7.178140E-04   0.0
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Listing 9-18 Output for Response to Impulsive Loading (Continued)

```
 1.460001E-01     G      0.0            0.0           -1.493984E-03  -2.958461E-03  -8.348633E-04   0.0
 1.470001E-01     G      0.0            0.0           -2.696360E-04  -1.161745E-03  -5.194459E-04   0.0
 1.480001E-01     G      0.0            0.0            1.684244E-03   2.685519E-03   6.588913E-04   0.0
 1.490001E-01     G      0.0            0.0            1.002875E-03   1.226687E-03   2.470292E-04   0.0
 1.500001E-01     G      0.0            0.0           -6.957233E-04  -2.232762E-03  -7.416279E-04   0.0
 1.510001E-01     G      0.0            0.0           -4.900639E-04  -1.113328E-03  -5.288565E-04   0.0
 1.520001E-01     G      0.0            0.0            6.023014E-04   2.037505E-03   7.820815E-04   0.0
 1.530001E-01     G      0.0            0.0           -2.351499E-04   8.511588E-04   4.781105E-04   0.0
 1.540001E-01     G      0.0            0.0           -1.380059E-03  -1.900070E-03  -2.816594E-04   0.0
 1.550001E-01     G      0.0            0.0           -6.787569E-04  -1.018426E-03  -3.198939E-04   0.0
 1.560001E-01     G      0.0            0.0            9.882766E-04   1.711110E-03   4.971909E-04   0.0
 1.570001E-01     G      0.0            0.0            9.362240E-04   9.626952E-04   1.674076E-04   0.0
 1.580001E-01     G      0.0            0.0            5.189726E-05  -1.327085E-03  -6.418804E-04   0.0
 1.590001E-01     G      0.0            0.0            1.955679E-04  -7.185966E-04  -4.638136E-04   0.0
 1.600001E-01     G      0.0            0.0            6.786224E-04   1.298382E-03   2.630581E-04   0.0
 1.610001E-01     G      0.0            0.0           -8.227860E-05   7.057204E-04   4.385834E-04   0.0
 1.620001E-01     G      0.0            0.0           -1.345931E-03  -1.331449E-03  -1.954969E-04   0.0
 1.630002E-01     G      0.0            0.0           -1.051940E-03  -8.056768E-04   5.613884E-05   0.0
 1.640002E-01     G      0.0            0.0            1.071181E-05   9.181313E-04   3.878956E-04   0.0
 1.650002E-01     G      0.0            0.0            4.550409E-04   7.198871E-04   3.102073E-04   0.0
 1.660002E-01     G      0.0            0.0            2.333840E-04  -8.213215E-04  -4.760102E-04   0.0
 1.670002E-01     G      0.0            0.0            7.116988E-04  -4.137290E-04  -4.676717E-04   0.0
 1.680002E-01     G      0.0            0.0            1.153325E-03   9.373685E-04  -3.286889E-05   0.0
 1.690002E-01     G      0.0            0.0            4.913089E-04   6.023816E-04   6.817585E-05   0.0
 1.700002E-01     G      0.0            0.0           -7.658474E-04  -7.955685E-04  -9.293895E-05   0.0
 1.710002E-01     G      0.0            0.0           -1.200295E-03  -7.098395E-04   1.382808E-05   0.0
 1.720002E-01     G      0.0            0.0           -7.489835E-04   4.777487E-04   5.672128E-04   0.0
 1.730002E-01     G      0.0            0.0           -5.185438E-04   3.266047E-04   3.524377E-04   0.0
 1.740002E-01     G      0.0            0.0           -2.042031E-04  -5.216984E-04  -3.804082E-05   0.0
 1.750002E-01     G      0.0            0.0            5.615253E-04  -3.326587E-04  -4.009234E-04   0.0
 1.760002E-01     G      0.0            0.0            1.487935E-03   7.536719E-04  -1.498162E-04   0.0
 1.770002E-01     G      0.0            0.0            1.273256E-03   5.774245E-04  -2.459310E-04   0.0
 1.780002E-01     G      0.0            0.0            3.024940E-04  -3.458402E-04  -3.141850E-04   0.0
 1.790002E-01     G      0.0            0.0           -5.688225E-04  -4.596818E-04  -8.242772E-05   0.0
 1.800002E-01     G      0.0            0.0           -9.792754E-04   1.816574E-04   3.824324E-04   0.0
 1.810002E-01     G      0.0            0.0           -1.274795E-03   1.023419E-04   5.850311E-04   0.0
 1.820002E-01     G      0.0            0.0           -1.241922E-03  -5.531911E-04   2.107370E-04   0.0
 1.830002E-01     G      0.0            0.0           -2.804317E-04  -3.115422E-04   7.864104E-05   0.0
 1.840002E-01     G      0.0            0.0            9.704945E-04   4.340205E-04  -1.594367E-04   0.0
 1.850002E-01     G      0.0            0.0            1.702863E-03   6.021237E-04  -2.549823E-04   0.0
 1.860002E-01     G      0.0            0.0            1.403530E-03  -2.958229E-05  -6.121827E-04   0.0
 1.870002E-01     G      0.0            0.0            7.665304E-04  -9.373976E-05  -3.773403E-04   0.0
 1.880002E-01     G      0.0            0.0           -1.959836E-04   1.585177E-04   3.192795E-05   0.0
 1.890002E-01     G      0.0            0.0           -1.251860E-03   8.339703E-06   4.258728E-04   0.0
 1.900002E-01     G      0.0            0.0           -1.988690E-03  -5.505313E-04   4.967770E-04   0.0
 1.910002E-01     G      0.0            0.0           -1.660003E-03  -5.022489E-04   4.024686E-04   0.0
 1.920002E-01     G      0.0            0.0           -3.841232E-04   1.249955E-04   3.376834E-04   0.0
 1.930002E-01     G      0.0            0.0            9.434439E-04   3.465624E-04  -1.410667E-04   0.0
 1.940002E-01     G      0.0            0.0            1.863529E-03   2.101642E-04  -4.862250E-04   0.0
 1.950002E-01     G      0.0            0.0            2.019248E-03   1.558693E-04  -7.712894E-04   0.0
 1.960002E-01     G      0.0            0.0            1.474028E-03   4.132012E-04  -3.943830E-04   0.0
 1.970002E-01     G      0.0            0.0           -1.839087E-05   1.189617E-04  -9.099875E-05   0.0
 1.980002E-01     G      0.0            0.0           -1.600760E-03  -3.883835E-04   3.585487E-04   0.0
 1.990002E-01     G      0.0            0.0           -2.515950E-03  -6.093766E-04   6.101881E-04   0.0
 2.000002E-01     G      0.0            0.0           -2.160876E-03  -2.693361E-04   7.338890E-04   0.0
 2.010002E-01     G      0.0            0.0           -9.102881E-04  -1.687789E-05   4.787360E-04   0.0
 2.020002E-01     G      0.0            0.0            7.480578E-04   4.728562E-05  -1.610488E-04   0.0
 2.030002E-01     G      0.0            0.0            2.278186E-03   3.079034E-04  -5.838384E-04   0.0
 2.040002E-01     G      0.0            0.0            2.869659E-03   5.649793E-04  -8.780280E-04   0.0
 2.050002E-01     G      0.0            0.0            2.179565E-03   5.141765E-04  -6.106258E-04   0.0
 2.060002E-01     G      0.0            0.0            2.587293E-04  -6.459943E-05  -3.323081E-04   0.0
 2.070002E-01     G      0.0            0.0           -1.725127E-03  -3.929432E-04   3.743645E-04   0.0
 2.080002E-01     G      0.0            0.0           -3.069415E-03  -5.150104E-04   8.119692E-04   0.0
 2.090002E-01     G      0.0            0.0           -3.034864E-03  -4.234743E-04   1.019369E-03   0.0
 2.100002E-01     G      0.0            0.0           -1.733352E-03  -3.575768E-04   6.235040E-04   0.0
 2.110002E-01     G      0.0            0.0            5.522765E-04   3.508538E-05  -3.043863E-05   0.0
 2.120003E-01     G      0.0            0.0            2.762739E-03   5.524859E-04  -6.237298E-04   0.0
 2.130003E-01     G      0.0            0.0            3.771152E-03   7.348440E-04  -1.094646E-03   0.0
 2.140003E-01     G      0.0            0.0            3.086632E-03   5.181605E-04  -9.666639E-04   0.0
 2.150003E-01     G      0.0            0.0            8.947147E-04   4.645199E-05  -5.669380E-04   0.0
 2.160003E-01     G      0.0            0.0           -1.700743E-03  -2.581777E-04   3.872023E-04   0.0
 2.170003E-01     G      0.0            0.0           -3.812307E-03  -6.525432E-04   9.693527E-04   0.0
 2.180003E-01     G      0.0            0.0           -4.218458E-03  -7.479748E-04   1.320671E-03   0.0
 2.190003E-01     G      0.0            0.0           -2.773780E-03  -5.561418E-04   9.163487E-04   0.0
 2.200003E-01     G      0.0            0.0            1.795202E-04   9.624101E-05   2.228875E-04   0.0
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Listing 9-18 Output for Response to Impulsive Loading (Continued)

```
   2.210003E-01     G      0.0             0.0             3.135700E-03   6.181641E-04  -6.947663E-04   0.0
   2.220003E-01     G      0.0             0.0             4.823594E-03   8.400299E-04  -1.381313E-03   0.0
   2.230003E-01     G      0.0             0.0             4.398130E-03   7.316995E-04  -1.382021E-03   0.0
   2.240003E-01     G      0.0             0.0             1.914227E-03   3.195525E-04  -8.579714E-04   0.0
   2.250003E-01     G      0.0             0.0            -1.567403E-03  -2.369589E-04   2.802343E-04   0.0
   2.260003E-01     G      0.0             0.0            -4.657363E-03  -8.873062E-04   1.104366E-03   0.0
   2.270003E-01     G      0.0             0.0            -5.652663E-03  -1.011140E-03   1.723242E-03   0.0
   2.280003E-01     G      0.0             0.0            -4.182603E-03  -7.403171E-04   1.361565E-03   0.0
   2.290003E-01     G      0.0             0.0            -5.780478E-04  -1.130328E-05   5.543356E-04   0.0
   2.300003E-01     G      0.0             0.0             3.378979E-03   5.921744E-04  -7.469959E-04   0.0
   2.310003E-01     G      0.0             0.0             6.118981E-03   1.079928E-03  -1.670057E-03   0.0
   2.320003E-01     G      0.0             0.0             6.153750E-03   1.087471E-03  -1.892052E-03   0.0
   2.330003E-01     G      0.0             0.0             3.356797E-03   5.936244E-04  -1.299945E-03   0.0
   2.340003E-01     G      0.0             0.0            -1.179238E-03  -2.381812E-04   3.281619E-05   0.0
   2.350003E-01     G      0.0             0.0            -5.484900E-03  -1.046208E-03   1.253870E-03   0.0
   2.360003E-01     G      0.0             0.0            -7.414041E-03  -1.284453E-03   2.216629E-03   0.0
   2.370003E-01     G      0.0             0.0            -6.144434E-03  -1.079112E-03   1.944911E-03   0.0
   2.380003E-01     G      0.0             0.0            -1.839957E-03  -2.625199E-04   1.012914E-03   0.0
   2.390003E-01     G      0.0             0.0             3.453881E-03   5.956089E-04  -6.963862E-04   0.0
   2.400003E-01     G      0.0             0.0             7.621572E-03   1.405847E-03  -1.962363E-03   0.0
   2.410003E-01     G      0.0             0.0             8.392469E-03   1.481200E-03  -2.554140E-03   0.0
   2.420003E-01     G      0.0             0.0             5.398798E-03   9.340101E-04  -1.930166E-03   0.0
   2.430003E-01     G      0.0             0.0            -3.302165E-04  -1.220906E-04  -3.671448E-04   0.0
   2.440003E-01     G      0.0             0.0            -6.230413E-03  -1.147759E-03   1.382003E-03   0.0
   2.450003E-01     G      0.0             0.0            -9.583949E-03  -1.677284E-03   2.766317E-03   0.0
   2.460003E-01     G      0.0             0.0            -8.785130E-03  -1.569489E-03   2.709697E-03   0.0
   2.470003E-01     G      0.0             0.0            -3.756500E-03  -6.016875E-04   1.678723E-03   0.0
   2.480003E-01     G      0.0             0.0             3.197917E-03   5.812791E-04  -4.917661E-04   0.0
   2.490003E-01     G      0.0             0.0             9.248429E-03   1.725327E-03  -2.266577E-03   0.0
   2.500003E-01     G      0.0             0.0             1.122016E-02   1.952431E-03  -3.379125E-03   0.0
   2.510003E-01     G      0.0             0.0             8.266538E-03   1.448477E-03  -2.778684E-03   0.0
   2.520003E-01     G      0.0             0.0             1.184665E-03   1.339732E-04  -9.854110E-04   0.0
   2.530003E-01     G      0.0             0.0            -6.792149E-03  -1.237627E-03   1.419625E-03   0.0
   2.540003E-01     G      0.0             0.0            -1.216930E-02  -2.180480E-03   3.363552E-03   0.0
   2.550003E-01     G      0.0             0.0            -1.223911E-02  -2.178696E-03   3.716870E-03   0.0
   2.560003E-01     G      0.0             0.0            -6.582852E-03  -1.086005E-03   2.615821E-03   0.0
   2.570002E-01     G      0.0             0.0             2.368485E-03   4.586253E-04  -7.517185E-05   0.0
   2.580002E-01     G      0.0             0.0             1.091072E-02   2.029289E-03  -2.547267E-03   0.0
   2.590002E-01     G      0.0             0.0             1.475148E-02   2.570610E-03  -4.359750E-03   0.0
   2.600002E-01     G      0.0             0.0             1.219281E-02   2.170888E-03  -3.910022E-03   0.0
   2.610002E-01     G      0.0             0.0             3.635037E-03   5.386329E-04  -1.919886E-03   0.0
   2.620002E-01     G      0.0             0.0            -6.961936E-03  -1.275574E-03   1.296542E-03   0.0
   2.630002E-01     G      0.0             0.0            -1.512885E-02  -2.751689E-03   3.996010E-03   0.0
   2.640001E-01     G      0.0             0.0            -1.668653E-02  -2.941853E-03   5.009115E-03   0.0
   2.650001E-01     G      0.0             0.0            -1.065038E-02  -1.810635E-03   3.893492E-03   0.0
   2.660001E-01     G      0.0             0.0             6.627294E-04   1.793185E-04   6.539468E-04   0.0
   2.670001E-01     G      0.0             0.0             1.245672E-02   2.318546E-03  -2.736659E-03   0.0
   2.680001E-01     G      0.0             0.0             1.905787E-02   3.352434E-03  -5.492821E-03   0.0
   2.690001E-01     G      0.0             0.0             1.744150E-02   3.119428E-03  -5.404855E-03   0.0
   2.700001E-01     G      0.0             0.0             7.399579E-03   1.160860E-03  -3.280084E-03   0.0
   2.710001E-01     G      0.0             0.0            -6.425262E-03  -1.182623E-03   9.231617E-04   0.0
   2.720000E-01     G      0.0             0.0            -1.838016E-02  -3.379212E-03   4.615506E-03   0.0
   2.730000E-01     G      0.0             0.0            -2.232134E-02  -3.914532E-03   6.620323E-03   0.0
   2.740000E-01     G      0.0             0.0            -1.635271E-02  -2.851291E-03   5.606419E-03   0.0
   2.750000E-01     G      0.0             0.0            -2.321702E-03  -3.010529E-04   1.838321E-03   0.0
   2.760000E-01     G      0.0             0.0             1.361780E-02   2.541347E-03  -2.745761E-03   0.0
   2.770000E-01     G      0.0             0.0             2.416934E-02   4.292966E-03  -6.765412E-03   0.0
   2.780000E-01     G      0.0             0.0             2.433116E-02   4.347008E-03  -7.340153E-03   0.0
   2.790000E-01     G      0.0             0.0             1.297826E-02   2.109392E-03  -5.202598E-03   0.0
   2.799999E-01     G      0.0             0.0            -4.747333E-03  -8.806002E-04   1.715333E-04   0.0
   2.809999E-01     G      0.0             0.0            -2.176146E-02  -4.057511E-03   5.125216E-03   0.0
   2.819999E-01     G      0.0             0.0            -2.930844E-02  -5.118906E-03   8.594471E-03   0.0
   2.829999E-01     G      0.0             0.0            -2.417504E-02  -4.297596E-03   7.860482E-03   0.0
   2.839999E-01     G      0.0             0.0            -7.122335E-03  -1.057946E-03   3.665930E-03   0.0
   2.849999E-01     G      0.0             0.0             1.395812E-02   2.588708E-03  -2.453377E-03   0.0
   2.859999E-01     G      0.0             0.0             3.008059E-02   5.414738E-03  -8.132558E-03   0.0
   2.869999E-01     G      0.0             0.0             3.320433E-02   5.909710E-03  -9.779184E-03   0.0
   2.879998E-01     G      0.0             0.0             2.100846E-02   3.507734E-03  -7.890218E-03   0.0
   2.889998E-01     G      0.0             0.0            -1.327078E-03  -2.676054E-04  -1.096041E-03   0.0
   2.899998E-01     G      0.0             0.0            -2.500460E-02  -4.769334E-03   5.328638E-03   0.0
   2.909998E-01     G      0.0             0.0            -3.772444E-02  -6.507999E-03   1.104175E-02   0.0
   2.919998E-01     G      0.0             0.0            -3.482290E-02  -6.369889E-03   1.069685E-02   0.0
   2.929998E-01     G      0.0             0.0            -1.427403E-02  -2.055919E-03   6.448292E-03   0.0
   2.939998E-01     G      0.0             0.0             1.261101E-02   2.119660E-03  -1.716477E-03   0.0
   2.949997E-01     G      0.0             0.0             3.705790E-02   7.018307E-03  -9.541666E-03   0.0
   2.959997E-01     G      0.0             0.0             4.398796E-02   7.507920E-03  -1.259255E-02   0.0
   2.969997E-01     G      0.0             0.0             3.281017E-02   5.891366E-03  -1.202309E-02   0.0
   2.979997E-01     G      0.0             0.0             4.413120E-03   5.459607E-04  -2.176007E-03   0.0
   2.989997E-01     G      0.0             0.0            -2.875510E-02  -6.116121E-03   3.274524E-03   0.0
   2.999997E-01     G      0.0             0.0            -1.085742E-02   1.394087E-02   1.216307E-02   0.0
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Listing 9-18 Output for Response to Impulsive Loading (Continued)

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3.009997E-01   G   0.0   0.0    1.766391E-03   6.902323E-04   6.124929E-03   0.0
3.019997E-01   G   0.0   0.0   -1.834716E-02  -3.249004E-02  -9.177285E-03   0.0
3.029996E-01   G   0.0   0.0   -5.634046E-03  -6.863975E-04   1.746809E-03   0.0
3.039996E-01   G   0.0   0.0    7.096197E-03   2.770672E-02   9.704980E-03   0.0
3.049996E-01   G   0.0   0.0   -5.864178E-03  -9.690460E-04   1.917567E-03   0.0
3.059996E-01   G   0.0   0.0   -1.496431E-02  -2.624627E-02  -7.773848E-03   0.0
3.069996E-01   G   0.0   0.0   -2.152263E-03  -1.309318E-03  -1.493671E-03   0.0
3.079996E-01   G   0.0   0.0    1.007565E-02   2.327812E-02   7.343920E-03   0.0
3.089996E-01   G   0.0   0.0    2.832067E-05   7.933610E-04   5.161318E-04   0.0
3.099996E-01   G   0.0   0.0   -8.526123E-03  -2.054936E-02  -6.364749E-03   0.0
3.109995E-01   G   0.0   0.0    5.856552E-04  -1.317151E-03  -1.786556E-03   0.0
3.119995E-01   G   0.0   0.0    9.585500E-03   1.909170E-02   5.962196E-03   0.0
3.129995E-01   G   0.0   0.0    9.524014E-04   1.540756E-03   8.510052E-04   0.0
3.139995E-01   G   0.0   0.0   -7.286367E-03  -1.674549E-02  -5.079296E-03   0.0
3.149995E-01   G   0.0   0.0   -4.487576E-04  -1.701517E-03  -1.173318E-03   0.0
3.159995E-01   G   0.0   0.0    6.697942E-03   1.513037E-02   4.758496E-03   0.0
3.169995E-01   G   0.0   0.0    3.291314E-04   1.797356E-03   1.313984E-03   0.0
3.179995E-01   G   0.0   0.0   -6.492182E-03  -1.373120E-02  -4.258122E-03   0.0
3.189994E-01   G   0.0   0.0   -5.850392E-04  -1.795491E-03  -8.981298E-04   0.0
3.199994E-01   G   0.0   0.0    5.594981E-03   1.215771E-02   3.524496E-03   0.0
3.209994E-01   G   0.0   0.0    9.434395E-04   2.047807E-03   1.185068E-03   0.0
3.219994E-01   G   0.0   0.0   -4.913731E-03  -1.104445E-02  -3.610261E-03   0.0
3.229994E-01   G   0.0   0.0   -5.457957E-04  -1.838428E-03  -9.004638E-04   0.0
3.239994E-01   G   0.0   0.0    4.353001E-03   9.774495E-03   2.912089E-03   0.0
3.249994E-01   G   0.0   0.0    5.005336E-04   1.917038E-03   1.091568E-03   0.0
3.259993E-01   G   0.0   0.0   -4.313071E-03  -8.899920E-03  -2.623410E-03   0.0
3.269993E-01   G   0.0   0.0   -8.822255E-04  -1.928860E-03  -8.925656E-04   0.0
3.279993E-01   G   0.0   0.0    3.667275E-03   7.955862E-03   2.493622E-03   0.0
3.289993E-01   G   0.0   0.0    8.584516E-04   1.842394E-03   7.256354E-04   0.0
3.299993E-01   G   0.0   0.0   -2.885107E-03  -6.986035E-03  -2.109552E-03   0.0
3.309993E-01   G   0.0   0.0   -4.639394E-04  -1.814380E-03  -1.052916E-03   0.0
3.319993E-01   G   0.0   0.0    3.107272E-03   6.449440E-03   1.998578E-03   0.0
3.329993E-01   G   0.0   0.0    5.230833E-04   1.656828E-03   6.765602E-04   0.0
3.339992E-01   G   0.0   0.0   -2.858792E-03  -5.695171E-03  -1.547721E-03   0.0
3.349992E-01   G   0.0   0.0   -1.057238E-03  -1.775701E-03  -6.898907E-04   0.0
3.359992E-01   G   0.0   0.0    2.090989E-03   5.074440E-03   1.649966E-03   0.0
3.369992E-01   G   0.0   0.0    5.855286E-04   1.586703E-03   7.323427E-04   0.0
3.379992E-01   G   0.0   0.0   -1.893007E-03  -4.531471E-03  -1.450125E-03   0.0
3.389992E-01   G   0.0   0.0   -1.954876E-04  -1.428696E-03  -6.847495E-04   0.0
3.399992E-01   G   0.0   0.0    2.239133E-03   4.109832E-03   1.005443E-03   0.0
3.409992E-01   G   0.0   0.0    8.513575E-04   1.534250E-03   6.233312E-04   0.0
3.419991E-01   G   0.0   0.0   -1.794120E-03  -3.711471E-03  -1.192173E-03   0.0
3.429991E-01   G   0.0   0.0   -8.552190E-04  -1.383589E-03  -3.842200E-04   0.0
3.439991E-01   G   0.0   0.0    9.818454E-04   3.125043E-03   1.020451E-03   0.0
3.449991E-01   G   0.0   0.0    1.700623E-04   1.266645E-03   7.190913E-04   0.0
3.459991E-01   G   0.0   0.0   -1.493627E-03  -2.956689E-03  -8.337529E-04   0.0
3.469991E-01   G   0.0   0.0   -2.722920E-04  -1.166522E-03  -5.209653E-04   0.0
3.479991E-01   G   0.0   0.0    1.683268E-03   2.683830E-03   6.585512E-04   0.0
3.489991E-01   G   0.0   0.0    1.004625E-03   1.230594E-03   2.479874E-04   0.0
3.499990E-01   G   0.0   0.0   -6.945509E-04  -2.230736E-03  -7.407800E-04   0.0
3.509990E-01   G   0.0   0.0   -4.914580E-04  -1.117147E-03  -5.302284E-04   0.0
3.519990E-01   G   0.0   0.0    6.020381E-04   2.035938E-03   7.813104E-04   0.0
3.529990E-01   G   0.0   0.0   -2.334317E-04   8.546368E-04   4.791183E-04   0.0
3.539990E-01   G   0.0   0.0   -1.379630E-03  -1.898591E-03  -2.811395E-04   0.0
3.549990E-01   G   0.0   0.0   -6.807937E-04  -1.021672E-03  -3.205045E-04   0.0
3.559990E-01   G   0.0   0.0    9.870963E-04   1.709569E-03   4.965789E-04   0.0
3.569990E-01   G   0.0   0.0    9.373573E-04   9.657767E-04   1.686769E-04   0.0
3.579989E-01   G   0.0   0.0    5.249940E-05  -1.325802E-03  -6.416096E-04   0.0
3.589989E-01   G   0.0   0.0    1.949151E-04  -7.211514E-04  -4.644895E-04   0.0
3.599989E-01   G   0.0   0.0    6.786276E-04   1.297060E-03   2.621408E-04   0.0
3.609989E-01   G   0.0   0.0   -8.058648E-05   7.082741E-04   4.392531E-04   0.0
3.619989E-01   G   0.0   0.0   -1.345312E-03  -1.330153E-03  -1.951410E-04   0.0
3.629989E-01   G   0.0   0.0   -1.053175E-03  -8.078989E-04   5.552897E-05   0.0
3.639989E-01   G   0.0   0.0    9.650893E-06   9.169857E-04   3.877376E-04   0.0
3.649988E-01   G   0.0   0.0    4.549030E-04   7.216685E-04   3.109371E-04   0.0
3.659988E-01   G   0.0   0.0    2.334058E-04  -8.201152E-04  -4.751335E-04   0.0
3.669988E-01   G   0.0   0.0    7.107151E-04  -4.156126E-04  -4.683674E-04   0.0
3.679988E-01   G   0.0   0.0    1.153458E-03   9.364379E-04  -3.314081E-05   0.0
3.689988E-01   G   0.0   0.0    4.928737E-04   6.041599E-04   6.816424E-05   0.0
3.699988E-01   G   0.0   0.0   -7.643981E-04  -7.941440E-04  -9.255492E-05   0.0
3.709988E-01   G   0.0   0.0   -1.200567E-03  -7.111878E-04   1.309348E-05   0.0
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Listing 9-18 Output for Response to Impulsive Loading (Continued)

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3.719988E-01    G    0.0            0.0          -7.495407E-04  4.767647E-04  5.669591E-04  0.0
3.729987E-01    G    0.0            0.0          -5.188594E-04  3.275825E-04  3.529138E-04  0.0
3.739987E-01    G    0.0            0.0          -2.048586E-04 -5.209335E-04 -3.739426E-05  0.0
3.749987E-01    G    0.0            0.0           5.599606E-04 -3.341018E-04 -4.008568E-04  0.0
3.759987E-01    G    0.0            0.0           1.487058E-03  7.525436E-04 -1.501879E-04  0.0
3.769987E-01    G    0.0            0.0           1.274628E-03  5.788830E-04 -2.454688E-04  0.0
3.779987E-01    G    0.0            0.0           3.040848E-04 -3.448114E-04 -3.144755E-04  0.0
3.789987E-01    G    0.0            0.0          -5.678338E-04 -4.606239E-04 -8.296494E-05  0.0
3.799987E-01    G    0.0            0.0          -9.789682E-04  1.807473E-04  3.815530E-04  0.0
3.809986E-01    G    0.0            0.0          -1.274341E-03  1.033490E-04  5.854531E-04  0.0
3.819986E-01    G    0.0            0.0          -1.242691E-03 -5.525769E-04  2.111366E-04  0.0
3.829986E-01    G    0.0            0.0          -2.823023E-04 -3.125830E-04  7.892682E-05  0.0
3.839986E-01    G    0.0            0.0           9.684587E-04  4.329739E-04 -1.591782E-04  0.0
3.849986E-01    G    0.0            0.0           1.702390E-03  6.026756E-04 -2.545648E-04  0.0
3.859986E-01    G    0.0            0.0           1.404470E-03 -2.862414E-05 -6.118199E-04  0.0
3.869986E-01    G    0.0            0.0           7.678129E-04 -9.405064E-05 -3.781085E-04  0.0
3.879986E-01    G    0.0            0.0          -1.939435E-04  1.582681E-04  3.128907E-05  0.0
3.889985E-01    G    0.0            0.0          -1.250422E-03  8.981047E-06  4.252739E-04  0.0
3.899985E-01    G    0.0            0.0          -1.988131E-03 -5.497173E-04  4.971457E-04  0.0
3.909985E-01    G    0.0            0.0          -1.661686E-03 -5.030980E-04  4.023444E-04  0.0
3.919985E-01    G    0.0            0.0          -3.864922E-04  1.240874E-04  3.383066E-04  0.0
3.929985E-01    G    0.0            0.0           9.413488E-04  3.463441E-04 -1.404991E-04  0.0
3.939985E-01    G    0.0            0.0           1.862532E-03  2.104558E-04 -4.855430E-04  0.0
3.949985E-01    G    0.0            0.0           2.019427E-03  1.554509E-04 -7.713680E-04  0.0
3.959984E-01    G    0.0            0.0           1.475807E-03  4.130549E-04 -3.951788E-04  0.0
3.969984E-01    G    0.0            0.0          -1.539207E-05  1.199204E-04 -9.146095E-05  0.0
3.979984E-01    G    0.0            0.0          -1.598186E-03 -3.876524E-04  3.576092E-04  0.0
3.989984E-01    G    0.0            0.0          -2.515437E-03 -6.096095E-04  6.100373E-04  0.0
3.999984E-01    G    0.0            0.0          -2.162746E-03 -2.701208E-04  7.337374E-04  0.0
```

10 Aeroelastic Design Sensitivities and Optimization

Overview

Aeroelastic design sensitivity and optimization are available in Solution 200. These capabilities are based on static aeroelastic analysis, Solution 144, and flutter analysis, Solution 145. Optimization of aeroelastic characteristics can therefore be combined with the other optimization features of Solution 200. Flight vehicles can then be designed optimally for aeroelastic loads, flying qualities, and flutter as well as for strength, vibration frequencies, and buckling characteristics. The theory, algorithms, and applications for aeroelastic optimization have been published by Neill, Johnson, and Canfield (1987) [Reference 36], Johnson and Venkayya (1988) [Reference 28], and Johnson and Reymond (1991) [Reference 29].

The specification of an aeroelastic design requires the specification of the response quantities that are to be included in the design process and the determination of these responses. MSC Nastran permits the specification of a number of responses for static analysis including displacements, stresses, strains, and forces, and these capabilities are available in static aeroelasticity. The response quantities for aeroelastic design include:

- Trim variables in a static aeroelastic response. These allow the user to design for limits imposed on, for example, the trim angle of attack or control surface travel.
- Stability derivatives. These allow the user to specify limits on, for example, the rolling effectiveness of an aileron.
- Flutter damping level. This assures flutter stability without a requirement to determine the actual flutter speed.

Once a quantity is identified as a response, it can be used directly in a constraint condition; in combination with other responses and/or design variables in a constraint condition; as an objective function directly; or in combination with other responses and/or design variables in the objective function. This capability of combining responses and design variables is a unique innovation in MSC Nastran.

The user interface for the design sensitivity and optimization capability builds on the existing interface for aeroelastic analysis as detailed in the this guide and on the interface for design optimization described in the *Design Sensitivity and Optimization User's Guide*. The integrated capability contains some aspects of the user interface that are unique to aeroelasticity.

Case Control

Two aeroelastic analysis types are available for the ANALYSIS command:

```
ANALYSIS = SAERO
ANALYSIS = FLUTTER
```

As the names imply, the ANALYSIS commands refer to static aeroelasticity and flutter analysis, respectively.

Bulk Data

Three response types for the DRESP1 entry are unique to aeroelasticity: TRIM, STABDER, and FLUTTER.

The TRIM response is used to identify an aerodynamic extra point that the user wants to study. This is done by identifying the variable (AESURF or AESTAT ID) in the ATTA field of the DRESP1 entry.

The STABDER response is used to identify a stability derivative. In addition to the aerodynamic variable, the user must identify the component (1 through 6) and if a restrained or unrestrained derivative is of interest.

The FLUTTER response allows the user selectively to identify damping responses that are to be studied. Attributes that are available for the response are mode number, Mach number, density, and velocity.

As with the input, the output is a combination of the existing aeroelastic and design optimization output. Perhaps the most valuable output available is the sensitivity matrix. This provides a quantitative assessment of how the responses change due to changes in the design variables [see pages 220-223 of the *MSC Nastran Design Sensitivity and Optimization User's Guide*. The effect of design changes on aeroelastic responses is often nonintuitive, even for the most experienced analyst. Therefore, the sensitivity matrix can provide substantial guidance when a design change is required or contemplated.

Aeroelastic Design Sensitivities of FSW Airplane (Example HA200A)

This example illustrates the design sensitivity features of SOLution 200 when aeroelastic constraints are included along with stress and deflection constraints. A final Example HA200B illustrates optimization. The Bulk Data sets are almost the same in the two examples with the differences noted at the end of the Bulk Data description contained in this section. These examples are based on the two-sided FSW airplane model of Example HA144E (p. 300). The two-sided model, shown in Figure 10-1, is chosen since some of the design flight conditions are asymmetric maneuvers. The optimization is intended to minimize the structural weight of the wings and fin, as indicated in Figure 10-2, with constraints on tensile and compressive stresses and wing tip twist during four subsonic and one supersonic maneuver. Additional constraints are imposed on subsonic and supersonic rolling effectiveness and on the flutter speed. Note that the two-sided model can flutter either symmetrically or antisymmetrically but that the mode of flutter is not a concern with the two-sided model.

The loading conditions are different from those analyzed in Example HA144E. The five flight conditions considered here are: (1) a subsonic pullout at $m = 0.9$ and $n_z = 6.0\text{ Gs}$; (2) a supersonic pullout at $m = 1.2$ and $n_z = 4.0\text{ Gs}$; (3) a subsonic steady rolling pullout at $m = 0.9$ and $n_z = 4.8\text{ Gs}$; (4) a subsonic abrupt rolling pullout at $m = 0.0$ and $n_z = 4.8\text{ Gs}$; and, (5) an entry into a snap-roll from level flight at $m = 0.45$.

For the sensitivity task of this example, the goal is to see what effect the CBAR elements, which represent the wing and fin structures, have on selected responses. In developing the design model, the first task is the definition of the design variables. In this case, it is first necessary to define independent design variables that have no explicit physical meaning except that the physical properties of the CBARs are linearly related to these design variables:

$$\begin{Bmatrix} A \\ I_1 \\ I_2 \\ J \end{Bmatrix} = \begin{Bmatrix} 1.500000 \\ 0.173611 \\ 2.000000 \\ 0.462963 \end{Bmatrix} x_i \tag{10-1}$$

where A, I_1, I_2, and J are the area, cross-section area moments of inertia, and effective torsional moment of inertia, respectively, of the i-th CBAR element. The design variable representing the inboard wing CBAR is x_1 and the vector of coefficients is chosen to reproduce the physical properties in Example HA144E when $x_1 = 1.0$. The same relationship is used to design the outboard wing CBAR using a second design variable x_2, and to design the fin CBAR using a third design variable x_3. The design of mass balances is another possible option for flutter prevention that is not considered in this example.

Anticipating the design optimization task of the next section (p. 769), a design objective of weight is defined in this section even though it is not required for the sensitivity task. The baseline input Example HA144E presents a problem since all of its mass data are input using CONM2 entries. The CONM2 entry as design parameters. In order to avoid this problem, the CONM2 values for the wing and fin are reduced to half of their values in Example HA144E values, and these values, may be regarded here as nonstructural mass; the nonstructural weight of each wing is now 1000 lbs, and the nonstructural weight of the fin is 50 lbs. The structural mass is then calculated by means of the CBAR cross-sectional area, A above, and its density on the MAT1 entry. For the wing, MAT1 2, is assigned a density of $38.49002\ \text{lbs/ft}^3$, and for the fin, MAT1 3, is assigned a density of $5.773503\ \text{lbs/ft}^3$. These values of density lead to a structural wing weight of 1000.0 lbs on each side and a structural fin weight of 50.0 lbs when the design variables $x_1 = x_2 = x_3 = 1.0$. There is a slight aft shift of the center of gravity from its location in Example HA144E as a consequence of this division in weight between structural and nonstructural portions (it has moved from 2.276 ft to 2.514 ft aft of GRID 90, that is, 2.38% of the mean aerodynamic chord).

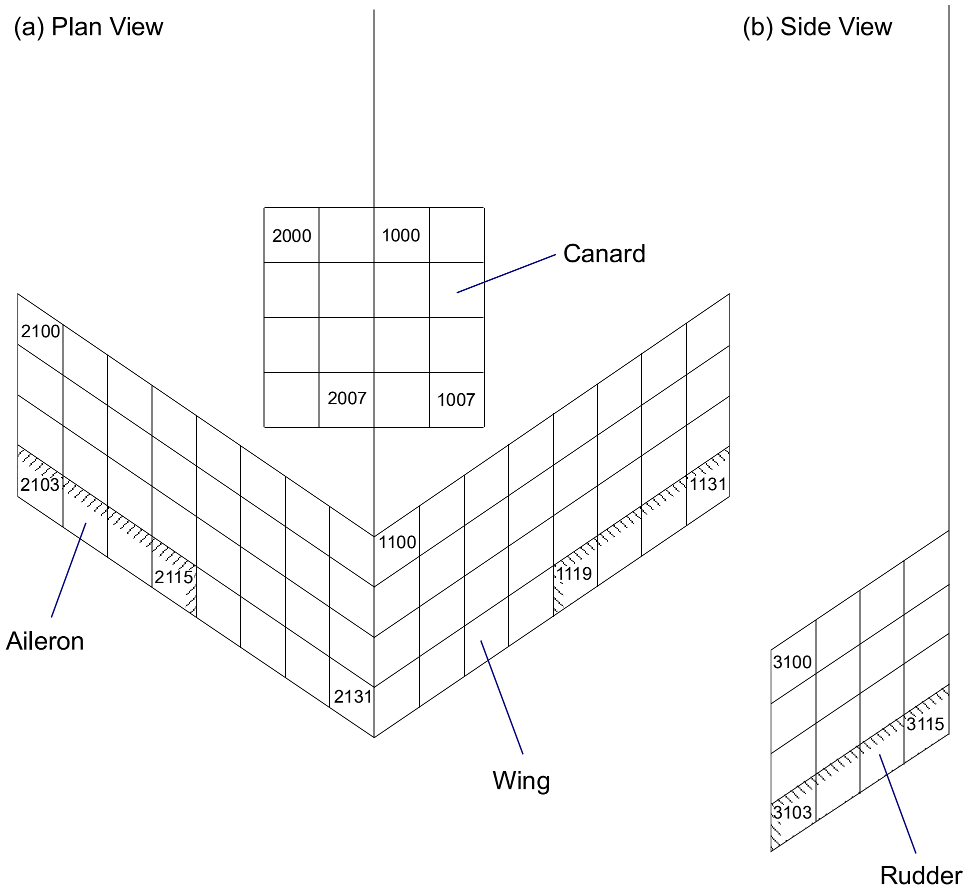

Figure 10-1 Aerodynamic Model of Example HA144E

The final step in the design model specification relates to constraint specifications. This example illustrates typical preliminary design considerations: strength of the aeroelastic airframe in high load factor maneuvers, stiffness in maneuvering for good aerodynamic performance, stiffness for adequate roll control, and stiffness for flutter prevention. These design considerations are each expressed as constraints. Strength is prescribed as a constraint on stresses. Stiffness in maneuvering is prescribed as a constraint on the twist at the wing tips. Stiffness for roll control is prescribed as a constraint on the rolling helix angle per unit aileron deflection. Finally, stiffness for flutter prevention is prescribed by constraints on the aeroelastic system damping at selected speeds in the flight envelope, including margins of safety on velocity.

The foregoing design considerations are implemented in MSC Nastran using the Bulk Data of Listing 10-1.

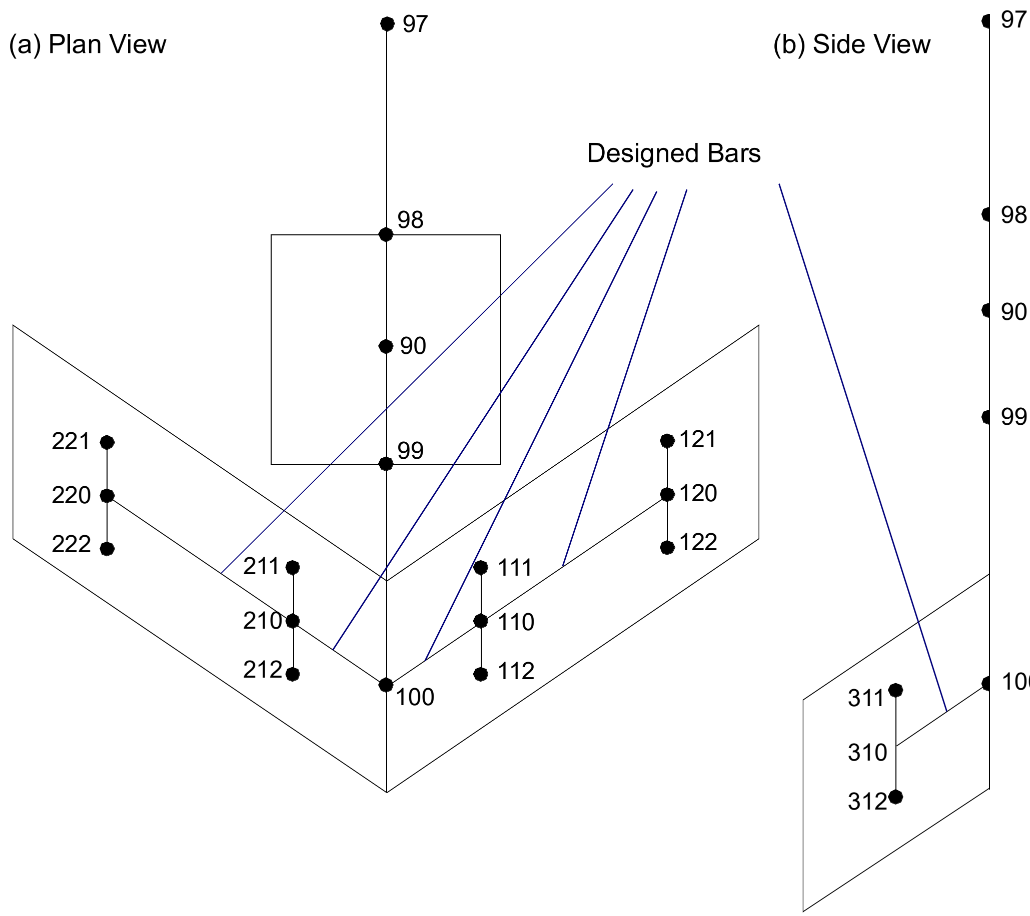

Figure 10-2 Structural Model of HA200A and HA200B

The listing begins with an INCLUDE entry for data set fswtwo.dat, which is given in Listing 7-18. This is followed by those parts of the structural model that differ from the Example HA144E (p. 300) description due to design considerations. For example, separate PIDs are now required on the CBAR Bulk Data entry so that the associated properties can be independently designed. The CONM2 and MAT1 entries have been modified to split the aircraft weight into nonstructural and structural portions, as described above. Five TRIM Bulk Data entries define the five maneuvering flight conditions that are used to design the structure, with the remaining static aeroelastic inputs provided in the INCLUDE file.

Input for the flutter analysis is in addition to that provided in Section and is therefore input in its entirety. A subsonic and a supersonic flutter analysis are specified with two separate FLUTTER Bulk Data entries and their corresponding FLFACT entries. PARAM,LMODES retains 12 modes in the flutter analysis.

Design Variables

The remainder of the input is for the design model and begins with a definition of the design variables on the DESVAR Bulk Data entries. Design variables 10, 20, and 30 control the properties on the inboard wing, outboard wing, and fin bars, respectively. Note that the initial fin design variable is 10 percent of the wing design variables, reflecting the designer's insight that the fin structure will require significantly less strength than that of the wing. The DVPREL1 entries indicate the linear relationships between the PBAR properties and the design variables as specified in (10-1).

Responses and Constraints

Responses required in the automated design task are identified using DRESP1 and DRESP2 Bulk Data entries. This example has considerable generality in that it contains DRESP1 entries for WEIGHT, STRESS, DISPlacement, STABDER (stability derivatives), and FLUTTER responses that are either constrained directly (that is, specified to be within limiting values), used in specifying the design objective (in this case it is to minimize the weight), or included in synthetic responses. The STRESS responses invoke the minimum and maximum stresses at end A (the end at the grid point mentioned first on the CBAR entry) of the bars that model the wing structure. DCONSTR entries then constrain these stresses to fall between -57.6 and 72.0×10^6 psf.

The ability to limit the structural deformations is demonstrated in this example by first identifying rotational displacements at the two wing tips and at the vehicle centerline. The difference between the tip and root displacement is a measure of the aeroelastic deformation, and the difference is effected using a DRESP2 entry that identifies the associated responses and a DEQATN entry that provides that equation the takes the difference. DCONSTR entries are used to limit the response to +1.0 degrees subsonically and +0.5 degrees supersonically. DCONADD entries adds these displacement constraints (plus a roll effectiveness constraint described next) to the already defined stress constraints. DCONADD 1 refers to the subsonic subcase while DCONADD 2 refers to the supersonic subcase.

The roll performance specification frequently determines the stiffness of an aircraft wing. This requirement is demonstrated in this example by selecting two stability responses,

$$C_{l_p} \text{ and } C_{l_{\delta_a}},$$

on DRESP1 entries and then defining an equation using the DRESP2 and DEQATN entries to specify a roll performance criterion

$$\frac{pb}{2V\delta_a} = -\frac{C_{l_{\delta_a}}}{C_{l_p}} \geq \text{REQUIREMENT} \tag{10-2}$$

DCONSTR entries are used to provide a lower limit of 0.60 for this criterion subsonically and 0.43 supersonically.

Main Index

Flutter Responses

Two sets of DRESP1 entries include subsonic and supersonic flutter responses in the design task. DRESP1 1 selects modal damping responses at the analysis density and Mach number, but only at three critical velocities: 1000.0, 1300.0 and 1500.0 ft/sec. These responses must all be available from the analysis. A SET1 entry invoked by the DRESP1 entry restricts the responses to the fourth through the seventh modes since the first three modes represent rigid body behavior that should not impact the structural design. DRESP1 11 performs the same function for the supersonic flutter analysis. DRESP2 entries convert the damping value to a new response of the form

$$\bar{\gamma} = (\gamma - 0.03) / 0.1 \tag{10-3}$$

This form offsets the response from zero and scales it (see Aeroelastic Modeling) so that the constraint imposed on the DCONSTR entry specifies that this response should be less than -0.3, which is equivalent to saying that the damping should be negative.

Optimization Parameters

The input file concludes with several entries that define parameters for the optimization and sensitivity task. The DOPTPRM entry is used primarily in optimization and in this case limits the number of design cycles to 25, requests a comprehensive printout of design details following each design cycle, and overrides the default finite difference step size DELB to give greater numerical accuracy when computing sensitivity values. PARAM,CDIF,YES invokes the more accurate central differencing technique for this example. PARAM,NASPRT,2 requests standard MSC Nastran output after every other design cycle. Even for this small model, this request results in extensive output so PARAM,NASPRT,2 must be used with caution. Two DSCREEN entries complete the Bulk Data input and, for this example, force the retention of all the constraints and therefore produce the sensitivities of all DRESP1 and DRESP2 responses. The DSCREEN and PARAM,CDIF entries are removed for the optimization example of the next section, and DELB is returned to its default value.

Case Control Commands

The Case Control Section begins with the TITLE and SUBTITLE commands. The ECHO = BOTH command echoes the input Bulk Data, including the "INCLUDEd" files in unsorted and sorted formats. A single boundary condition is used for all the analyses and is selected by the SPC = 1 command. The DESOBJ = 10 request invokes the Bulk Data DRESP1 entry with ID = 10 as the objective. This is the WEIGHT response. Request for output of all the DISPlacments, STRESSes, element FORCEs, AEROdynamic Forces, and Aerodynamic PRESsures is made above the subcase level, which means that the requests apply to all the subcases until they are cancelled in subcases 6 and 7. The DSAPRT(END=SENS) command tells the program to stop after printing the design sensitivity results and to not proceed onto the optimization phase. Seven subcases follow, with each subcase defined by a unique LABEL. The first five subcases are static aeroelastic trim analyses for differing maneuvering conditions. The ANALYSIS = SAERO command is required in these subcases to identify which of the multidisciplinary analyses applies for the subcase. The TRIM command selects a TRIM Bulk Data entry that specifies the maneuver. For the first subcase, the DESSUB = 1 command invokes the DCONADD Bulk Data entry with DCID = 1 which, in turn, invokes limits on the element stresses, the aeroelastic deformation, and the roll performance for the subsonic flight condition. The second subcase invokes a similar set of constraints for the supersonic flight condition. The remaining three static aeroelastic subcases only constrain the stress responses.

The final two subcases involve the flutter design tasks, as indicated by the ANALYSIS = FLUTTER commands. The sixth subcase, and the first flutter subcase, includes a DISP = 10 request along with PARAM,OPPHIPA set to 1 so as to obtain normal mode displacements at the grid points. SET 10 is used to limit to the displacement output to the aerodynamic box centers and not the box corners. The remaining output requests are set to NONE to avoid output of these data for eigenvectors. The METHOD and FMETHOD entries are familiar from Flutter Analysis Problems, 407 and invoke the normal modes and flutter analysis, respectively. The DESSUB = 6 command invokes a DCONSTR entry that places limits on the subsonic flutter responses. The DESSUB = 7 command of the final subcase performs the same function for the supersonic flutter analysis.

The Executive Control Section begins with the identification ID MSC, HA200A, which denotes the problem in the Test Problem Library. TIME 30 limits the CPU time to 30 minutes, and SOL 200 invokes the design sensitivity and optimization solution sequence.

Output

Selected output is in Listing 10-2 and only includes those aspects of the output that are unique to design sensitivity since the lengthy remaining output has been covered by the examples in Static Aeroelastic Analysis Problems, 199 and Flutter Analysis Problems, 407. An exception to this is that the subsonic flutter results are shown to assist in the discussion of the flutter sensitivity results. The first table shown in Listing 10-2 contains information on the properties that are being designed. In the table, the “ANALYSIS VALUE” refers to the values of the properties as they are input on the property entries (PBAR in this example) while the “DESIGN MODEL” refers to the values of the properties developed from the design model input on the DESVAR and DVPREL1 entries. These two values can differ, and the user is warned if they do. In this example, the properties on the fin for the design model are a tenth of the analysis properties. This was the user's intent so the warning can be ignored. Limits on the property values are also displayed in this table.

The flutter summary for the subsonic flutter analysis is shown next. It is seen that flutter occurs for point 7 between 1300.0 and 1400.0 ft/sec.

The Design Optimization results which follow in Listing 10-2 is optional information that is produced by setting P2=15 on the DOPTPRM entry. In this case, the results are for the initial analysis and include the design objective, design variables, designed properties, design constraints, property constraints (there are none in this example), followed by design responses. Type one responses that are based on DRESP1 input are followed by DRESP2 responses. Internal response 73 is a flutter response where the damping value is a positive 0.438. Applying (10-3), this becomes modified value of 0.408 which is DRESP2 response with an internal id of 18 for the retained DRESP2 responses. If we look back at the constraints, internal constraint 128 has a value of 14.605 and points to the internal response id 18 just discussed. This is marked as the maximum constraint response from the current analysis.

The Design Sensitivity Information

MSC Nastran produces a sensitivity matrix with rows that correspond to the design variables and the columns correspond to the responses. A formatted form of this matrix is output next in Listing 10-2. This output provides information that is valuable to the analyst in its own right. For example, the first sensitivity is for the weight and is seen that the sensitivity of the weight with respect to the three design variables is 666.83,1333.0 and 49.998, respectively. While this particular sensitivity is predictable and could be calculated by hand, other sensitivity values are not available with a computer analysis. For example, the internal DRESP2 response id 18 discussed above is associated with subcase 6, DRESP2 ID 4 and for the response value of 0.408, it is seen that the sensitivities for the three design variables are -0.5986,-0.2431 and -.01510, respectively.

This provides the analyst/designer with useful information on the tradeoffs required to improve the flutter performance of the vehicle. In this particular case, it is seen that increasing the first design variable is the most cost effective strategy; that is, achieves the most increase in flutter damping for a unit change in weight.

Design Variable Identification

The final information in Listing 10-2 is the design cycle history and the design variable history. This information is most useful in an optimization task, but it also is useful for the sensitivity analysis since it identifies the design variable labels and values and therefore allows the user to quickly interpret the physical meaning of the rows of the design sensitivity matrix.

Listing 10-1 Input File for Design Sensitivities of FSW Airplane

```
 ID MSC, HA200A $ E_JOHNSON V68  5-JUL-1994
     $$$$$$$$  HANDBOOK FOR AEROELASTIC ANALYSIS EXAMPLE HA200A      $$$$$$$$
     $                                                                      $
     $       MODEL DESCRIPTION         FULL SPAN 30 DEG FWD SWEPT WING      $
     $                                 WITH AILERON, CANARD AND AFT SWEPT   $
     $                                 VERTICAL FIN AND RUDDER.             $
     $                                 BAR MODEL WITH DUMBBELL MASSES.      $
     $                                                                      $
     $       SOLUTION                  QUASI-STEADY AEROELASTIC ANALYSIS    $
     $                                 AND UNSTEADY FLUTTER ANALYSIS USING  $
     $                                 DOUBLET-LATTICE METHOD               $
     $                                 AERODYNAMICS AT MACH NO. 0.9.        $
     $                                                                      $
     $       OUTPUT                    STANDARD AEROELASTIC OUTPUT PLUS     $
     $                                 A TABLE IDENTIFYING RESPONSES        $
     $                                 FOR WHICH SENSITIVITY RESULTS ARE    $
     $                                 AVAILABLE FOLLOWED BY A MATRIX OF    $
     $                                 SENSITIVITY VALUES.                  $
     $                                                                      $
     $                                                                      $
     $$$$$$$$                                                        $$$$$$$$
     TIME 30 $ CPU TIME IN MINUTES
     SOL 200 $ OPTIMIZATION WITH AEROELASTICITY
     CEND
0                                C A S E   C O N T R O L   E C H O
              COMMAND
              COUNT
                 1      TITLE = EXAMPLE HA200A: 30 DEG FWD SWEPT WING WITH CANARD AND  HA200A
                 2      SUBTI  = DEMONSTRATION OF AEROELASTIC SENSITIVITY ANALYSIS
                 3       ECHO   = BOTH
                 4       SPC    = 1
                 5       DESOBJ = 10
                 6       DISP     = ALL $
                 7       STRESS   = ALL $
                 8       FORCE    = ALL $
                 9       AEROF    = ALL $
                10       APRES    = ALL $
                11       DSAPRT(END=SENS)
                12        SUBCASE 1
```

Listing 10-1 Input File for Design Sensitivities of FSW Airplane (Continued)

```
 13        LABEL    = SUBSONIC SYMMETRIC PULLOUT
 14        ANALYSIS = SAERO
 15        DESSUB   = 1
 16        TRIM     = 1 $
 17      SUBCASE 2
 18        LABEL    = SUPERSONIC SYMMETRIC PULLOUT
 19        ANALYSIS = SAERO
 20        DESSUB   = 2
 21        TRIM     = 2 $
 22      SUBCASE 3
 23        LABEL    = HIGH SPEED ROLLING PULLOUT
 24        ANALYSIS = SAERO
 25        DESSUB   = 200
 26        TRIM     = 3 $
 27      SUBCASE 4
 28        LABEL    = HIGH SPEED PULLUP WITH ABRUPT ROLL
 29        ANALYSIS = SAERO
 30        DESSUB   = 200
 31        TRIM     = 4 $
 32      SUBCASE 5
 33        LABEL    = SUBSONIC ENTRY INTO SNAP ROLL
 34        ANALYSIS = SAERO
 35        DESSUB  = 200
 36        TRIM    = 5 $
 37      SUBCASE 6
 38        LABEL    = SUBSONIC FLUTTER ANALYSIS
 39        ANALYSIS = FLUTTER
 40        SET 10   = 1,THRU,100000
 41        PARAM      OPPHIPA,1
 42        DISP     = 10
 43        STRESS   = NONE $
 44        FORCE    = NONE $
 45        AEROF    = NONE $
 46        APRES    = NONE $
 47        DESSUB   = 6
 48        METHOD   = 20
 49        FMETHOD  = 30
 50      SUBCASE 7
 51        LABEL    = SUPERSONIC FLUTTER ANALYSIS
 52        ANALYSIS = FLUTTER
 53        DISP     = NONE $
 54        STRESS   = NONE $
 55        FORCE    = NONE $
 56        AEROF    = NONE $
 57        APRES    = NONE $
 58        DESSUB   = 7
 59        METHOD   = 20
 60        FMETHOD  = 40
 61       BEGIN BULK
                    I N P U T   B U L K   D A T A   E C H O
ENTRY
COUNT      .  1 ..  2  ..  3  ..  4  ..  5  ..  6  ..  7  ..  8  ..  9  ..  10  .
   93-        $
 $INCLUDE "/devl/builds/Nastran/BUG-FIX/665661/all/nastran/msc20200/nast/MSC_DOC_DIR/tpl/include/fswtwo.dat"
    1-        $ DEC/CMS REPLACEMENT HISTORY, Element FSWTWO.DAT
    2-        $ *1     5-JUL-1994 16:46:14 A_BOYADJIAN "68 PLUS/G/ NEW FOR V68 AERO_SS BOOK"
    3-        $ DEC/CMS REPLACEMENT HISTORY, Element FSWTWO.DAT
    4-        $*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***$
    5-        $                                                                        $
    6-        $                     * * * STRUCTURAL DATA * * *                        $
    7-        $                                                                        $
    8-        $                          (LB-FT-SEC SYSTEM)                            $
    9-        $                                                                        $
   10-        $                       * * GRID GEOMETRY * *                            $
   11-        $                                                                        $
   12-        $       GRID  90 - 100 (T3) FUSELAGE POINTS                              $
   13-        $       GRID 110 - 122 (T3) WING POINTS                                  $
   14-        $       GRID 310 - 312 (t3) FIN POINTS                                   $
   15-        $                                                                        $
   16-        $                          * FUSELAGE GRID *                             $
   17-        $                                                                        $
```

Listing 10-1 Input File for Design Sensitivities of FSW Airplane (Continued)

```
$        THE GRID ENTRY DEFINES THE LOCATION OF A STRUCTURAL GRID       $
$        POINT.  LISTED ARE ITS COORDINATE SYSTEM ID, ITS LOCATION,     $
$        THE ID OF THE COORDINATE SYSTEM IN WHICH ITS DISPLACEMENTS     $
$        ARE DEFINED, ITS PERMANENT SINGLE-POINT CONSTRAINTS AND        $
$        ITS ASSOCIATED SUPERELEMENT ID.                                $
$                                                                       $
$       ID      CP      X1      X2      X3      CD      PS      SEID
GRID    90              15.     0.      0.
GRID    97              0.      0.      0.
GRID    98              10.     0.      0.
GRID    99              20.     0.      0.
GRID    100             30.     0.      0.
$                                                                       $
$                         * RIGHT WING GRID *                           $
$                                                                       $
$       ID      CP      X1      X2      X3      CD      PS      SEID
GRID    111             24.61325 +5.    0.
GRID    110             27.11325 +5.    0.
GRID    112             29.61325 +5.    0.
GRID    121             18.83975+15.    0.
GRID    120             21.33975+15.    0.
GRID    122             23.83975+15.    0.
$                                                                       $
$                         * LEFT WING GRID *                            $
$                                                                       $
$       ID      CP      X1      X2      X3      CD      PS      SEID
GRID    211             24.61325 -5.    0.
GRID    210             27.11325 -5.    0.
GRID    212             29.61325 -5.    0.
GRID    221             18.83975-15.    0.
GRID    220             21.33975-15.    0.
GRID    222             23.83975-15.    0.
$                                                                       $
$                             * FIN GRID *                              $
$                                                                       $
GRID    310             32.88675+0.     5.
GRID    311             30.38675+0.     5.
GRID    312             35.38675+0.     5.
$                                                                       $
$                * * STRUCTURAL STIFFNESS PROPERTIES * *                $
$                                                                       $
$                        * FUSELAGE STRUCTURE *                         $
$                                                                       $
$        THE CBAR ENTRY DEFINES A SIMPLE BEAM ELEMENT.  LISTED ARE      $
$        ITS PROPERTY ENTRY ID, THE TWO GRID POINTS JOINED BY THE       $
$        BEAM AND COMPONENTS OF A VECTOR FROM THE FIRST POINT.          $
$        THIS VECTOR DEFINES THE DIRECTION OF THE STRUCTURAL DE-        $
$        FLECTION OF THE POINT AND ITS POSITIVE SENSE.                  $
$                                                                       $
$       EID     PID     GA      GB      X1,GO   X2      X3
CBAR    101     100     97      98      0.      0.      1.
CBAR    102     100     98      90      0.      0.      1.
CBAR    103     100     90      99      0.      0.      1.
CBAR    104     100     99      100     0.      0.      1.
$                                                                       $
$        THE PBAR ENTRY DEFINES GEOMETRIC PROPERTIES OF THE BEAM.       $
$        LISTED ARE ITS ASSOCIATED MATERIAL ENTRY ID, ITS CROSS SEC-    $
$        TIONAL AREA, AREA MOMENTS OF INERTIA, TORSIONAL MOMENT         $
$        OF INERTIA AND NON-STRUCTURAL MASS PER UNIT AREA.  THE         $
$        OPTIONAL CONTINUATION ENTRY CONTAINS STRESS RECOVERY           $
$        COEFFICIENTS, I.E., Y,Z COORDINATES WHERE STRESSES ARE         $
$        TO BE COMPUTED.  K1 AND K2 ARE AREA FACTORS FOR SHEAR          $
$        STIFFNESS (DEFAULT IS BLANK; THEN SHEAR STIFFNESS IS           $
$        INFINITE, I.E., SHEAR FLEXIBILITY IS ZERO.  I12 IS THE         $
$        AREA PRODUCT OF INERTIA.                                       $
$                                                                       $
$       PID     MID     A       I1      I2      J       NSM
PBAR    100     1       4.0     .347222 .30     1.0                     +PB1F
$       C1      C2      D1      D2      E1      E2      F1      F2
+PB1F   1.0     1.0     1.0     -1.0    -1.0    1.0     -1.0    -1.0    +PB2F
$       K1      K2      I12
+PB2F                   0.0
$                                                                       $
```

Listing 10-1 Input File for Design Sensitivities of FSW Airplane (Continued)

```
$        THE MAT1 ENTRY DEFINES THE MATERIAL PROPERTIES.  LISTED        $
$        ARE ITS ID, ITS ELASTIC MODULUS, SHEAR MODULUS, POISSONS       $
$        RATIO, MASS DENSITY, TEMPERATURE EXPANSION COEFFICIENT,        $
$        REFERENCE TEMPERATURE AND A STRUCTURAL DAMPING COEFFICIENT.    $
$                                                                       $
$MAT1   MID     E       G       NU      RHO     A       TREF    GE      +MT
MAT1    1       1.44+9  5.40+8          0.0
$
$
$                 * * MASS AND INERTIA PROPERTIES * *                   $
$                                                                       $
$                          * FUSELAGE MASSES *                          $
$                                                                       $
$        THE CONM2 ENTRY DEFINES A CONCENTRATED MASS.  LISTED ARE       $
$        ITS ID, GRID LOCATION, COORDINATE SYSTEM TO LOCATE THE         $
$        CENTER OF GRAVITY, THE MASS VALUE AND THE LOCATION OF          $
$        THE CENTER OF GRAVITY RELATIVE TO THE GRID LOCATION.           $
$                                                                       $
$       EID     G       CID     M       X1      X2      X3
CONM2   97      97      0       3000.0
CONM2   98      98      0       3000.0
CONM2   99      99      0       3000.0
CONM2   100     100     0       3000.0
$                                                                       $
$                    * * STRUCTURAL PARAMETERS * *                      $
$                                                                       $
$        THE PARAM,GRDPNT,XX ENTRY CAUSES THE GRID POINT WEIGHT         $
$        GENERATOR TO BE EXECUTED USING GRID POINT XX AS THE REF-       $
$        ERENCE POINT.  THEN THE INERTIA MATRIX, THE TRANSFER MATRIX    $
$        FROM BASIC TO PRINCIPAL AXES AND OTHER PERTINENT INERTIA       $
$        DATA ARE PRINTED.                                              $
$                                                                       $
PARAM   GRDPNT  90
$                                                                       $
$        THE PARAM,WTMASS,GINV CAUSES ALL THE STRUCTURAL MASSES AND     $
$        MASS DENSITIES TO BE MULTIPLIED BY GINV (I.E., BY ONE OVER     $
$        THE ACCELERATION OF GRAVITY).  THE DYNAMIC PRESSURE SUPPLIED   $
$        FOR AERODYNAMIC FORCE CALCULATIONS WILL NOT BE MULTIPLIED      $
$        BY GINV.                                                       $
$                                                                       $
PARAM   WTMASS  .031081
$
$        THE PARAM,AUNITS,GINV PERMITS THE ACCELERATIONS ON THE TRIM
$        ENTRY TO BE SPECIFIED IN UNITS OF LOAD FACTOR (I.E., IN G'S)
$
PARAM   AUNITS  .031081
$                                                                       $
$                     * * STRUCTURAL CONSTRAINTS * *                    $
$                                                                       $
$        THE SPC1 ENTRY CONSTRAINS THE LISTED GRID POINTS IN THE        $
$        SPECIFIED DOF COMPONENTS.                                      $
$                                                                       $
$       SID     C       G1      G2      G3      G4
SPC1    1       1       90
$                                                                       $
$        THE SUPORT ENTRY IDENTIFIES A GRID POINT OR A SCALAR POINT     $
$        AND SPECIFIES THE DOF COMPONENTS IN WHICH THE USER DESIRES     $
$        REACTIONS TO BE APPLIED TO PREVENT RIGID BODY MOTION.  IT      $
$        THUS INVOKES THE SOLUTION OF THE BALANCE EQUATIONS TO DETER-   $
$        MINE THE REACTIONS.  IN THE STATIC AEROELASTIC SOLUTION        $
$        THE DOF COMPONENTS MUST BE CONSISTENT WITH THE UNDEFINED       $
$        VARIABLES ON THE TRIM ENTRIES.                                 $
$                                                                       $
$       ID      C
SUPORT  90      23456
$                                                                       $
$        THE OMIT1 ENTRY IDENTIFIES GRID POINTS TO BE OMITTED FROM      $
$        THE REMAINDER OF THE ANALYSIS.                                 $
$                                                                       $
$       ID      G       G       G       G
OMIT1   4       110     120     210     220     310
$                                                                       $
$                      * * * AERODYNAMIC DATA * * *                     $
```

Listing 10-1 Input File for Design Sensitivities of FSW Airplane (Continued)

```
$                                                                       $
$                           (LB-FT-SEC SYSTEM)                          $
$                                                                       $
$                        * * ELEMENT GEOMETRY * *                       $
$                                                                       $
$        THE AEROS ENTRY IS UNIQUE TO THE STATIC AEROELASTICITY         $
$        SOLUTION, SOL144. ACSID IDENTIFIES THE AERO COORDINATE         $
$        SYSTEM, RCSID IDENTIFIES THE REFERENCE COORDINATE SYS-         $
$        TEM FOR RIGID BODY MOTION.  REFC IS THE REFERENCE CHORD.       $
$        REFB IS THE REFERENCE SPAN.  REFS IS THE REFERENCE WING        $
$        AREA.  SYMXZ AND SYMXY ARE SYMMETRY KEYS.                      $
$                                                                       $
$       ACSID   RCSID   REFC    REFB    REFS    SYMXZ   SYMXY
AEROS   1       100     10.0    40.0    400.0
$                                                                       $
$        THIS CORD2R ENTRY DEFINES THE AERO COORDINATE SYSTEM           $
$        FLAGGED BY THE AEROS ENTRY.  THE ORIGIN IS AT THE CANARD       $
$        QUARTER CHORD.  LISTED ARE THE ORIGIN, A POINT ALONG THE       $
$        Z AXIS AND A POINT IN THE X-Z PLANE, ALL IN THE RID            $
$        COORDINATE SYSTEM.                                             $
$                                                                       $
$       CID     RID     A1      A2      A3      B1      B2      B3
CORD2R  1       0       12.5    0.      0.      12.5    0.      10.     +CRD1
$       C1      C2      C3
+CRD1   20.     0.      0.
$                                                                       $
$        THIS CORD2R ENTRY DEFINES THE NACA COORDINATE SYSTEM TO        $
$        WHICH ALL THE STABILITY DERIVATIVES AND TRIM CONDITIONS        $
$        WILL BE REFERENCED.                                            $
$                                                                       $
$       CID     RID     A1      A2      A3      B1      B2      B3
CORD2R  100     0       15.0    0.0     0.0     15.0    0.0     -10.0   +CRD100
$       C1      C2      C3
+CRD100 0.0     0.0     0.0
$                                                                       $
$                                                                       $
$                       * WING AERODYNAMIC MODEL *                      $
$                                                                       $
$        THE CAERO1 ENTRY IS USED FOR DOUBLET-LATTICE AERODYNAMICS.     $
$        LISTED ARE ITS PAERO ENTRY ID AND THE COORDINATE SYSTEM        $
$        FOR LOCATING THE INBOARD AND OUTBOARD LEADING EDGE POINTS      $
$        (1 AND 4).  NSPAN AND NCHORD, OR LSPAN AND LCHORD, ARE         $
$        USED TO PARTITION THE WING INTO AERODYNAMIC PANELS,            $
$        THE FORMER FOR UNIFORMLY SPACED PANELS AND THE LATTER          $
$        FOR NON-UNIFORMLY SPACED PANELS.  IGID IS THE ID OF ITS        $
$        ASSOCIATED INTERFERENCE GROUP.  THE CONTINUATION ENTRY         $
$        DEFINES POINTS 1 AND 4, THE ROOT CHORD AND TIP CHORD.          $
$        THE BOXES FORMED BY THE GRID LINES WILL BE NUMBERED            $
$        BEGINNING WITH EID SO CHOOSE A NUMBER THAT IS UNIQUE,          $
$        AND IS GREATER THAN ALL STRUCTURAL GRID, SCALAR AND            $
$        EXTRA POINT IDS.                                               $
$                                                                       $
$                           * RIGHT WING *
$       EID     PID     CP      NSPAN   NCHORD  LSPAN   LCHORD  IGID
CAERO1  1100    1000            8       4                       1       +CARW
$      ( FWD LEFT POINT  )     CHORD ( FWD RIGHT POINT   )     CHORD
$       X1      Y1      Z1      X12     X4          Y4    Z4      X14
+CARW   25.     0.      0.      10.     13.45299+20.    0.      10.
$                                                                       $
$        THE PAERO1 ENTRY IS REQUIRED EVEN THOUGH IT IS NON-FUNCTIONAL  $
$        (BECAUSE THERE ARE NO ASSOCIATED BODIES IN THIS EXAMPLE).      $
$                                                                       $
$       PID     B1      B2      B3      B4      B5      B6
PAERO1  1000
$                                                                       $
$                           * LEFT WING *
CAERO1  2100    1000            8       4                       1       +CALW
+CALW   13.45299-20.    0.      10.     25.     0.      0.      10.
$                                                                       $
$                      * CANARD AERODYNAMIC MODEL *                     $
$                                                                       $
$                            * RIGHT SIDE *
```

Listing 10-1 Input File for Design Sensitivities of FSW Airplane (Continued)

```
CAERO1  1000    1000            2       4                       1       +CARC
+CARC   10.     0.      0.      10.     10.     5.      0.      10.
$                                                                       $
$                            * LEFT SIDE *
CAERO1  2000    1000            2       4                       1       +CALC
+CALC   10.     -5.     0.      10.     10.     0.      0.      10.
$                                                                       $
$                       * FIN AERODYNAMIC MODEL *                       $
$                                                                       $
CAERO1  3100    1000            4       4                       1       +CA1FI
+CA1FI  30.7735 0.      10.     10.     25.     0.      0.      10.
$                                                                       $
$                * * SPLINE FIT ON THE LIFTING SURFACES * *             $
$                                                                       $
$                     * BEAM SPLINE FIT ON THE WING *                   $
$                                                                       $
$        THE SPLINE2 ENTRY SPECIFIES A BEAM SPLINE FOR INTERPOLAT-      $
$        ION OVER THE REGION OF THE CAERO ENTRY (ID1 AND ID2 ARE        $
$        THE FIRST AND LAST BOXES IN THIS REGION).  SETG REFERS         $
$        TO A SET1 ENTRY WHERE THE STRUCTURAL GRID POINTS ARE           $
$        DEFINED.  DZ AND DTOR ARE SMOOTHING CONSTANTS FOR LINEAR       $
$        ATTACHMENT AND TORSIONAL FLEXIBILITIES.  CID IDENTIFIES        $
$        THE CORD2R ENTRY THAT DEFINES THE SPLINE AXIS.  DTHX AND       $
$        DTHY ARE ROTATIONAL ATTACHMENT FLEXIBILITIES (-1. SPECIFIES    $
$        NO ATTACHMENT).                                                $
$                                                                       $
$                           * RIGHT WING *                              $
$       EID     CAERO   ID1     ID2     SETG    DZ      DTOR    CID
SPLINE2 1601    1100    1100    1131    1100    0.      1.      2       +SPRW
$       DTHX    DTHY
+SPRW   -1.     -1.
$                                                                       $
$        THE SET1 ENTRY DEFINES THE SETS OF STRUCTURAL GRID POINTS      $
$        TO BE USED BY THE BEAM SPLINE FOR INTERPOLATION.               $
$                                                                       $
$       SID     G1      G2      G3      G4
SET1    1100    99      100     111     112     121     122
$                                                                       $
$                           * LEFT WING *                               $
$       EID     CAERO   ID1     ID2     SETG    DZ      DTOR    CID
SPLINE2 2601    2100    2100    2131    2100    0.      1.      20      +SPLW
$       DTHX    DTHY
+SPLW   -1.     -1.
$                                                                       $
$        THE SET1 ENTRY DEFINES THE SETS OF STRUCTURAL GRID POINTS      $
$        TO BE USED BY THE BEAM SPLINE FOR INTERPOLATION.               $
$                                                                       $
$       SID     G1      G2      G3      G4
SET1    2100    99      100     211     212     221     222
$                                                                       $
$                  * BEAM SPLINE FIT ON THE CANARD *                    $
$                                                                       $
$                          * RIGHT SIDE *                               $
SPLINE2 1501    1000    1000    1007    1000    0.      1.      1       +SPRC
+SPRC   1.      -1.
$                                                                       $
SET1    1000    98      99
$                                                                       $
$                          * LEFT SIDE *                                $
SPLINE2 2501    2000    2000    2007    1000    0.      1.      1       +SPLC
+SPLC   1.      -1.
$                                                                       $
$                    * BEAM SPLINE FIT ON THE FIN *                     $
$                                                                       $
SPLINE2 3100    3100    3100    3115    3100    0.      1.      300     +SP2FI
+SP2FI  -1.     -1.
$                                                                       $
SET1    3100    99      100     311     312
$                                                                       $
$        THE CORD2R ENTRY DEFINES THE COORDINATE SYSTEM IN WHICH THE    $
$        BEAM SPLINE EXTENDS ALONG THE WING Y-AXIS.  IT LISTS THE       $
$        ORIGIN, A POINT ALONG THE Z-AXIS AND A POINT IN THE X-Z        $
$        PLANE.                                                         $
```

Listing 10-1 Input File for Design Sensitivities of FSW Airplane (Continued)

```
$                                                                       $
$                         * RIGHT WING SPLINE AXIS *                    $
$                                                                       $
$       CID     CS      A1      A2      A3      B1      B2      B3
CORD2R  2       0       30.     0.      0.      30.     0.      10.     +CRD2RW
$       C1      C2      C3
+CRD2RW 38.66025+5.0    0.
$                                                                       $
$                         * LEFT WING SPLINE AXIS *                     $
$                                                                       $
$       CID     CS      A1      A2      A3      B1      B2      B3
CORD2R  20      0       30.     0.      0.      30.     0.      10.     +CRD2LW
$       C1      C2      C3
+CRD2LW 38.66025-5.0    0.
$                                                                       $
$                          * FIN SPLINE AXIS *                          $
$                                                                       $
CORD2R  300     0       30.0    0.      0.      30.0    10.0    0.      +CRD2FI
+CRD2FI 20.0    0.0     5.7735
$                                                                       $
$                  * CONTROL SURFACE DEFINITION *                       $
$                                                                       $
$        THE AESURF ENTRY DEFINES AN AERODYNAMIC CONTROL SURFACE.       $
$        LISTED ARE THE ALPHANUMERIC NAME OF THE SURFACE, THE ID        $
$        OF A COORDINATE SYSTEM THAT DEFINES THE HINGE LINE AND         $
$        THE ID OF AN AELIST ENTRY.                                     $
$                                                                       $
$       ID      LABEL   CID1    ALID1   CID2    ALID2
AESURF  505     ELEV    1       1000    1       2000
AESURF  517     AILERON 110     1100    210     2100
AESURF  518     RUDDER  301     3000
$                                                                       $
$        THE AELIST ENTRY LISTS AERODYNAMIC BOXES THAT LIE ON THE       $
$        CONTROL SURFACE.                                               $
$                                                                       $
$       SID     E1      E2      E3      ETC
AELIST  1000    1000    THRU    1007
AELIST  2000    2000    THRU    2007
AELIST  1100    1119    1123    1127    1131
AELIST  2100    2103    2107    2111    2115
AELIST  3000    3103    3107    3111    3115
$                                                                       $
$                    * CONTROL SURFACE HINGE LINES *                    $
$                                                                       $
$                            * CANARD *                                 $
$        THE COORDINATE SYSTEM, CORD2R,1, REFERENCED BY THE AEROS ENTRY $
$        IS THE CANARD HINGE LINE, AND NEEDS NO FURTHER DEFINITION      $
$                                                                       $
$                         * RIGHT AILERON *                             $
CORD2R  110     0       26.7265 10.0    0.      26.7265 10.0    -10.0   +CRD2RA
+CRD2RA 36.7265 15.7735 0.
$                                                                       $
$                         * LEFT AILERON *                              $
CORD2R  210     0       26.7265 -10.0   0.      26.7265 -10.0   10.0    +CRD2LA
+CRD2LA 36.7265 -15.7735 0.
$                                                                       $
$                             * RUDDER *                                $
CORD2R  301     0       32.5    0.      0.      32.5    -10.    0.0     +CRD2R
+CRD2R  22.5    0.      5.7735
$                                                                       $
$
$                       * * AERODYNAMIC DOFS * *                        $
$                                                                       $
$        THE AESTAT ENTRY LISTS TRIM VARIABLES USED TO SPECIFY          $
$        RIGID BODY MOTIONS.  THESE AND THE CONTROL SURFACE             $
$        ROTATIONS MAKE UP THE VARIABLES IN THE EQUATIONS OF            $
$        MOTION.                                                        $
$                                                                       $
$       ID      LABEL
AESTAT  501     ANGLEA
AESTAT  502     PITCH
```

Listing 10-1 Input File for Design Sensitivities of FSW Airplane (Continued)

```
AESTAT  503     URDD3
AESTAT  504     URDD5
AESTAT  511     SIDES
AESTAT  512     YAW
AESTAT  513     ROLL
AESTAT  514     URDD2
AESTAT  515     URDD4
AESTAT  516     URDD6
$END OF INCLUDE "/devl/builds/Nastran/BUG-
FIX/665661/all/nastran/msc20200/nast/MSC_DOC_DIR/tpl/include/fswtwo.dat"
$
$                       * RIGHT WING STRUCTURE *                      $
$                                                                      $
$        THE CBAR ENTRY DEFINES A SIMPLE BEAM ELEMENT.  LISTED ARE     $
$        ITS PROPERTY ENTRY ID, THE TWO GRID POINTS JOINED BY THE      $
$        BEAM AND COMPONENTS OF A VECTOR FROM THE FIRST POINT.         $
$        THIS VECTOR DEFINES THE DIRECTION OF THE STRUCTURAL DE-       $
$        FLECTION OF THE POINT AND ITS POSITIVE SENSE.                 $
$                                                                      $
$       EID     PID     GA      GB      X1,GO   X2      X3
CBAR    110     101     100     110     0.      0.      1.
CBAR    120     102     110     120     0.      0.      1.
$                                                                      $
$        THE RBAR ENTRY DEFINES A RIGID BAR.  LISTED ARE THE GRID      $
$        POINTS AT EACH END AND THE DEPENDENT AND INDEPENDENT DOFS     $
$        AT EACH END.  THE NUMBER OF INDEPENDENT DOFS AT THE TWO       $
$        ENDS MUST EQUAL SIX.  BY DEFAULT THOSE NOT DECLARED INDE-     $
$        PENDENT ARE MADE DEPENDENT.                                   $
$                                                                      $
$       EID     GA      GB      CNA     CNB     CMA     CMB
RBAR    111     110     111     123456
RBAR    112     110     112     123456
RBAR    121     120     121     123456
RBAR    122     120     122     123456
$
$        THE PBAR ENTRY DEFINES GEOMETRIC PROPERTIES OF THE BEAM.      $
$        LISTED ARE ITS ASSOCIATED MATERIAL ENTRY ID, ITS CROSS SEC-   $
$        TIONAL AREA, AREA MOMENTS OF INERTIA, TORSIONAL MOMENT        $
$        OF INERTIA AND NON-STRUCTURAL MASS PER UNIT AREA.  THE        $
$        OPTIONAL CONTINUATION ENTRY CONTAINS STRESS RECOVERY          $
$        COEFFICIENTS, I.E., Y,Z COORDINATES WHERE STRESSES ARE        $
$        TO BE COMPUTED.  K1 AND K2 ARE AREA FACTORS FOR SHEAR         $
$        STIFFNESS (DEFAULT IS BLANK; THEN SHEAR STIFFNESS IS          $
$        INFINITE, I.E., SHEAR FLEXIBILITY IS ZERO.  I12 IS THE        $
$        AREA PRODUCT OF INERTIA.                                      $
$                                                                      $
$ INBOARD WING
$
$       PID     MID     A       I1      I2      J       NSM
PBAR    101     2       1.5     0.173611+2.0    0.462963                +PB1W
$       C1      C2      D1      D2      E1      E2      F1      F2
+PB1W   0.5     3.0     0.5     -3.0    -0.5    3.0     -0.5    -3.0    +PB2W
$       K1      K2      I12
+PB2W                   0.0
$
$ OUTBOARD WING
$
$       PID     MID     A       I1      I2      J       NSM
PBAR    102     2       1.5     0.173611+2.0    0.462963                +PB3W
$       C1      C2      D1      D2      E1      E2      F1      F2
+PB3W   0.5     3.0     0.5     -3.0    -0.5    3.0     -0.5    -3.0    +PB4W
$       K1      K2      I12
+PB4W                   0.0
$                                                                      $
$                        * LEFT WING STRUCTURE *                       $
$                                                                      $
$       EID     PID     GA      GB      X1,GO   X2      X3
CBAR    210     101     100     210     0.      0.      1.
CBAR    220     102     210     220     0.      0.      1.
$
$       EID     GA      GB      CNA     CNB     CMA     CMB
RBAR    211     210     211     123456
```

Listing 10-1 Input File for Design Sensitivities of FSW Airplane (Continued)

```
RBAR    212     210     212     123456
RBAR    221     220     221     123456
RBAR    222     220     222     123456
$                                                                       $
$                           * FIN STRUCTURE *                           $
$                                                                       $
$       EID     PID     GA      GB      X1,GO   X2      X3
CBAR    310     103     100     310     0.      0.      1.
$                                                                       $
$       PID     MID     A       I1      I2      J       NSM
PBAR    103     3       1.5     0.173611+2.0    0.462963                +PB1V
$       C1      C2      D1      D2      E1      E2      F1      F2
+PB1V   0.5     3.0     0.5     -3.0    -0.5    3.0     -0.5    -3.0    +PB2V
$       K1      K2      I12
+PB2V                   0.0
$
$       EID     GA      GB      CNA     CNB     CMA     CMB
RBAR    311     310     311     123456
RBAR    312     310     312     123456
$
$                                                                       $
$        THE MAT1 ENTRY DEFINES THE MATERIAL PROPERTIES.  LISTED        $
$        ARE ITS ID, ITS ELASTIC MODULUS, SHEAR MODULUS, POISSONS       $
$        RATIO, MASS DENSITY, TEMPERATURE EXPANSION COEFFICIENT,        $
$        REFERENCE TEMPERATURE AND A STRUCTURAL DAMPING COEFFICIENT.    $
$                                                                       $
$   DENSITY HAS BEEN ADJUSTED TO GIVE A WEIGHT OF 333.333 LBS FOR THE
$   INBOARD BAR AND 666.667 LBS FOR THE OUTBOARD BAR WHEN X1 = X2 = 1.0
$   AND 50.0 LBS FOR THE FIN WHEN X3 = 1.0
$
$       MID     E       G       NU      RHO     A       TREF    GE
MAT1    2       1.44+9  5.40+8          38.49002                        +MT2
$+MAT1  ST      SC      SS      MCSID
+MT2    7.20+6  5.76+6
MAT1    3       1.44+9  5.40+8          5.773503                        +MT3
+MT3    7.20+6  5.76+6
$                                                                       $
$                     *  WING AND FIN MASSES  *                         $
$                                                                       $
$        THE CONM2 ENTRY DEFINES A CONCENTRATED MASS.  LISTED ARE       $
$        ITS ID, GRID LOCATION, COORDINATE SYSTEM TO LOCATE THE         $
$        CENTER OF GRAVITY, THE MASS VALUE AND THE LOCATION OF          $
$        THE CENTER OF GRAVITY RELATIVE TO THE GRID LOCATION.           $
$                                                                       $
$ RIGHT WING
$
CONM2   111     111     0       300.0
CONM2   112     112     0       200.0
CONM2   121     121     0       300.0
CONM2   122     122     0       200.0
$                                                                       $
$ LEFT WING
$                                                                       $
CONM2   211     211     0       300.0
CONM2   212     212     0       200.0
CONM2   221     221     0       300.0
CONM2   222     222     0       200.0
$                                                                       $
$ FIN
$
CONM2   311     311     0       30.0
CONM2   312     312     0       20.0
$                                                                       $
$                        * * TRIM CONDITIONS * *                        $
$                                                                       $
$        THE TRIM ENTRY SPECIFIES CONSTRAINTS FOR THE TRIM VARIABLES    $
$        LISTED ON THE AESTAT AND AESURF ENTRYS.  LISTED ARE ITS ID,    $
$        THE MACH NUMBER, DYNAMIC PRESSURE AND PAIRS OF TRIM VARI-      $
$        ABLES AND THEIR CONSTRAINED VALUES.  THOSE THAT ARE NOT        $
$        HELD FIXED MUST BE CONSTRAINED BY REACTION FORCES STIPU-       $
$        LATED ON THE SUPORT ENTRY.  SEE SECTION 3.5.3 OF THE THEO-     $
```

Listing 10-1 Input File for Design Sensitivities of FSW Airplane (Continued)

```
$        RETICAL MANUAL FOR MORE DETAILS.                               $
$                                                                       $
$        TRIM CONDITION 1: SUBSONIC SYMMETRIC PULLOUT                   $
$                                                                       $
$       ID      MACH    Q       LABEL1  UX1     LABEL2  UX2             +TRM
TRIM    1       0.9     1200.0  PITCH   0.0     URDD3   -6.0            +TR1A
$       LABEL3  UX3     ETC
+TR1A   URDD5   0.0     AILERON 0.0     RUDDER  0.0     URDD2   0.0     +TR1B
+TR1B   URDD4   0.0     URDD6   0.0
$                                                                       $
$        TRIM CONDITION 2: SUPERSONIC SYMMETRIC PULLOUT                 $
$
TRIM    2       1.2     863.0   PITCH   0.      URDD3   -4.0            +TR2A
+TR2A   URDD5   0.0     AILERON 0.0     RUDDER  0.0     URDD2   0.0     +TR2B
+TR2B   URDD4   0.0     URDD6   0.0
$                                                                       $
$        TRIM CONDITION 3: HIGH SPEED ROLLING PULLOUT                   $
$                                                                       $
TRIM    3       0.9     1200.0  PITCH   6.0499-4URDD3   -4.8            +TR3A
+TR3A   URDD5   0.      AILERON .174533 YAW     0.      URDD2   0.      +TR3B
+TR3B   URDD4   0.      URDD6   0.
$                                                                       $
$        TRIM CONDITION 4: HIGH SPEED PULLUP WITH ABRUPT ROLL           $
$                                                                       $
TRIM    4       0.9     1200.0   PITCH  6.0499-4URDD3   -4.8            +TR4A
+TR4A   URDD5   0.      AILERON .174533 ROLL    0.      YAW     0.      +TR4B
+TR4B   URDD2   0.      URDD6   0.
$                                                                       $
$        TRIM CONDITION 5: SUBSONIC ENTRY INTO SNAP-ROLL                $
$                                                                       $
TRIM    5       0.45    300.0   ANGLEA  .0031512ELEV    .174533         +TR5A
+TR5A   PITCH   0.      SIDES   0.      ROLL    0.      YAW     0.      +TR5B
+TR5B   AILERON 0.      RUDDER  .174533
$                                                                       $
$                                 * * *                                 $
$
$                                                                       $
$                   * * *  FLUTTER ANALYSIS  * * *
$
$                          * AERODYNAMICS *
$
$        THE AERO ENTRY SPECIFIES THE AERO COORDINATE SYSTEM, THE       $
$        REFERENCE LENGTHS PLUS SYMMETRY KEYS.  SYMXZ = 0 INDICATES     $
$        THAT THE MODEL IS MOUNTED WITH NO ROOT REFLECTION PLANE;       $
$        SYMXY = 0 INDICATES THAT THE MODEL IS MOUNTED FAR ENOUGH       $
$        FROM THE FLOOR SO THAT REFLECTION EFFECTS ARE NEGLIGIBLE.      $
$                                                                       $
$       ACSID   VELOCITY REFC   RHOREF  SYMXZ   SYMXY
AERO    1               10.0    2.378-3
$
$        ALL COMBINATIONS OF MACH NUMBER AND REDUCED FREQUENCY LISTED   $
$        ON THE MKAERO1 ENTRY AND ITS CONTINUATION ENTRY WILL BE USED   $
$        TO GENERATE GENERALIZED AERO FORCE MATRICES.  IF MORE THAN     $
$        EIGHT MACH NOS OR REDUCED FREQUENCIES ARE REQUIRED A SECOND    $
$        MKAERO1 IS NECESSARY.                                          $
$                                                                       $
$MKAERO1 M1      M2      ETC                                            +MK
MKAERO1 0.90    1.20                                                    +MK
$+MK     K1      K2      K3      K4      K5      ETC
+MK     0.001   0.01    0.1     0.3     0.5     1.0
$
$
$                       * VIBRATION ANALYSIS *                          $
$                                                                       $
$        THE EIGR ENTRY SPECIFIES THE METHOD OF EXTRACTING THE EIGEN-   $
$        SOLUTIONS OF THE STRUCTURE IN A VACUUM, IN THIS CASE AN        $
$        AUTOMATIC SELECTION OF EITHER THE GIVENS METHOD OR THE         $
$        MODIFIED GIVENS METHOD.  THREE MODES ARE DESIRED, NORMAL-      $
$        IZED ON THE MAXIMUM DISPLACEMENTS.                             $
$                                                                       $
$EIGR   SID     METHOD  F1      F2              NO                      +EIGR
EIGR    20      AGIV                            15                      +AGIV
$       NORM    G       C                                               $
```

Listing 10-1 Input File for Design Sensitivities of FSW Airplane (Continued)

```
+AGIV   MAX
$
$        THE PARAM, OPPHIPA = 1 (WHEN ACCOMPANIED BY A DISPLACEMENT
$        REQUEST IN THE CASE CONTROL SECTION) WILL GENERATE THE
$        VIBRATION MODE DISPLACEMENTS FOR BOTH THE STRUCTURAL GRID
$        POINTS AND THE AERODYNAMIC GRID POINTS (BOX CENTERLINE
$        MIDPOINTS) IN THE OUTPUT.
$
PARAM   OPPHIPA 1
$
$
$                 * * FLUTTER SOLUTION PARAMETERS * *                  $
$                                                                      $
$        THE FLUTTER ENTRY DEFINES THE METHOD OF SOLUTION, IDENTIFIES  $
$        THE FLFACT ENTRIES THAT FOLL0W, SPECIFIES THE INTERPOLATION   $
$        METHOD, THE NUMBER OF ROOTS DESIRED IN THE OUTPUT AND THE     $
$        CRITERION FOR CONVERGENCE (DEFAULT IS 10-3).                  $
$                                                                      $
$       SID     METHOD  DENS    MACH    VEL     IMETH   NVALUE  EPS     $
FLUTTER 30      PK      1       2       3       S       8
$
$        FLFACT ENTRIES ARE USED TO SPECIFY DENSITY RATIOS, MACH NOS    $
$        AND REDUCED FREQUENCIES/VELOCITIES FOR FLUTTER ANALYSES.       $
$        NEGATIVE VELOCITIES ARE SIGNALS TO COMPUTE AND PRINT EIGEN-    $
$        VECTORS.                                                       $
$                                                                       $
$       SID     F1      F2      F3      F4      F5      F6      F7      $
FLFACT  1       1.0                                                     DENSITY
FLFACT  2       0.90                                                    MACH
FLFACT  3       1000.0  1100.0  1200.0  1300.0  1400.0  1500.0  1600.0  VELOCITY
FLUTTER 40      PK      11      12      13      S       8
FLFACT  11      1.0
FLFACT  12      1.20
FLFACT  13      1000.0  1100.0  1200.0  1300.0  1400.0  1500.0  1600.0
$
$        THE PARAM, LMODES, N, ENTRY SPECIFIES THAT N MODES ARE TO BE
$        USED IN THE FLUTTER ANALYSIS.
$
PARAM   LMODES  12
$
$                        *   *   *   *
$
$                  * * *  OPTIMIZATION  * * *
$
$
$                     *       *       *
$
$                    * THE DESIGN MODEL *
$
$ DEFINITION OF THE DESIGN VARIABLES
$
$        THE DESVAR ENTRY DEFINES A DESIGN VARIABLE FOR DESIGN
$        OPTIMIZATION.  LISTED ARE A UNIQUE DESIGN VARIABLE ID
$        NUMBER, A USER SUPPLIED NAME FOR PRINTING PURPOSES, AN
$        INITIAL VALUE, A LOWER BOUND, AND AN UPPER BOUND.
$
$DESVAR ID      LABEL   XINIT   XLB     XUB
DESVAR  10      PBAR101 1.0     0.001   100.0
DESVAR  20      PBAR102 1.0     0.001   100.0
DESVAR  30      PBAR103 0.1     0.001   100.0
$
$ RELATIONSHIP OF DESIGN VARIABLES TO ANALYSIS MODEL PROPERTIES
$
$        THE DVPREL1 ENTRY EXPRESSES AN AN ANALYSIS MODEL PROPERTY AS
$        A LINEAR FUNCTION OF DESIGN VARIABLES.  IT LISTS A UNIQUE ID,
$        AN ANALYSIS MODEL ENTRY TYPE ID STRING, A PROPERTY ENTRY ID,
$        THE FIELD POSITION OF THE PROPERTY ENTRY OR WORD POSITION IN
$        THE ELEMENT PROPERTY TABLE OF THE ANALYSIS MODEL, THE MINIMUM
$        AND MAXIMUM VALUES ALLOWED FOR THIS PROPERTY DURING OPTIMIZATION,
$        A CONSTANT TERM OF RELATION, A DESIGN VARIABLE ENTRY (DESVAR)
$        ID, AND A COEFFICIENT OF LINEAR RELATION.  THE EQUATION IS PI
```

Listing 10-1 Input File for Design Sensitivities of FSW Airplane (Continued)

```
$        = CO + CJXJ AND THE CONTINUATION ENTRY CAN BE USED TO LIST
$        MORE THAN ONE CJ.  IN THIS CASE, THERE IS ONLY ONE CJ FOR EACH
$        DVPREL1 ENTRY.
$
$DVPREL1ID      TYPE    PID     FID     PMIN    PMAX    C0      XXXX    +DVPREL1
DVPREL1 1014    PBAR    101     4
$       DVID1   COEF1   DVID2   COEF2   DVID3   COEF3   ....
+       10      1.5
DVPREL1 1015    PBAR    101     5
+       10      0.173611
DVPREL1 1016    PBAR    101     6
+       10      2.0
DVPREL1 1017    PBAR    101     7
+       10      0.462963
DVPREL1 1024    PBAR    102     4
+       20      1.5
DVPREL1 1025    PBAR    102     5
+       20      0.173611
DVPREL1 1026    PBAR    102     6
+       20      2.0
DVPREL1 1027    PBAR    102     7
+       20      .462963
DVPREL1 1028    PBAR    103     4
+       30      1.5
DVPREL1 1029    PBAR    103     5
+       30      0.173611
DVPREL1 1030    PBAR    103     6
+       30      2.0
DVPREL1 1031    PBAR    103     7
+       30      .462963
$
$                       *       *       *
$
$               * STRUCTURAL RESPONSES AND CONSTRAINTS *
$
$        THE DRESP1 ENTRY DEFINES A SET OF STRUCTURAL RESPONSES THAT
$        IS USED IN THE DESIGN EITHER AS CONSTRAINTS OR AS AN OBJECTIVE.
$        IT LISTS A UNIQUE ENTRY IDENTIFIER, A USER DEFINED LABEL, THE
$        THE RESPONSE TYPE, THE PROPERTY ENTRY TYPE OR ELEMENT ID FLAG
$        (ELEM), A REGION IDENTIFIER FOR CONSTRAINT SCREENING, AND A
$        NUMBER OF ATTRIBUTES DEFINED IN THE TABLE GIVEN IN THE DRESP1
$        BULK DATA ENTRY DESCRIPTION (SEE EITHER THE MSC/NASTRAN USERS
$        MANUAL, THE DESIGN OPTIMIZATION USERS GUIDE, OR THE QUICK
$        REFERENCE GUIDE).
$
$        DRESP1,10, IDENTIFIES THE
$        WEIGHT RESPONSE USED AS THE OBJECTIVE FUNCTION.
$
$DRESP1 ID      LABEL   RTYPE   PTYPE   REGION  ATTA    ATTB    ATT1
DRESP1  10      WEIGHT  WEIGHT
$
$        THE FOLLOWING DRESP1 ENTRIES IDENTIFY MAXIMUM AND MINIMUM
$        STRESSES AT END A OF ALL ELEMENTS IN PROPERTY GROUPS 101,
$        102, AND 103.  THE STRESS ITEM CODES LISTED IN THE ATTA
$        FIELDS CAN BE FOUND IN SECTION 4 OF THE MSC/NASTRAN USERS
$        MANUAL.
$
$ STRESS RESPONSES
$
$DRESP1 ID      LABEL   RTYPE   PTYPE   REGION  ATTA    ATTB    ATT1
DRESP1  1001    TEN110  STRESS  PBAR            7               101
+       102     103
DRESP1  1002    COM110  STRESS  PBAR            8               101
+       102     103
$
$ STRESS CONSTRAINTS
$
$        THE DCONSTR ENTRY DEFINES DESIGN CONSTRAINTS.  LISTED ARE
$        A CONSTRAINT SET ID, THE DRESPI ENTRY ID AND THE LOWER AND
$        UPPER BOUND IMPOSED ON THIS RESPONSE QUANTITY.  THE FOLLOWING
$        TWO ENTRIES IMPOSE LIMITS ON THE ALLOWABLE STRESSES IN THE
$        BARS IN UNITS OF POUNDS/FOOT**2.
$
```

Listing 10-1 Input File for Design Sensitivities of FSW Airplane (Continued)

```
$DCONSTR DCID    RID     LALLOW  UALLOW
DCONSTR 200     1001    -5.76+6 7.20+6
DCONSTR 200     1002    -5.76+6 7.20+6
$
$
$ TIP TWIST RESPONSES
$
DRESP1  101     RTIPROT DISP                    5               120
DRESP1  201     LTIPROT DISP                    5               220
DRESP1  100     RTROT   DISP                    5               100
$
$ SECOND LEVEL RESPONSES FOR TIP TWIST
$
$        THE DRESP2 ENTRY DEFINES THE INPUT ARGUMENTS TO USER-SUPPLIED
$        EQUATIONS.  THESE SECOND-LEVEL RESPONSES CAN THEN EITHER BE
$        USED AS CONSTRAINTS OR AS AN OBJECTIVE FUNCTION.  INPUT MAY
$        CONSIST OF DESIGN VARIABLES (DESVAR), FIRST-LEVEL (DRESP1)
$        RESPONSES, TABLE CONSTANTS (DTABLE), AND GRID COORDINATES
$        (DVGRID).  IT LISTS AN ID, A USER DEFINED LABEL, THE DEQATN
$        ENTRY ID, A REGION IDENTIFIER FOR CONSTRAINT SCREENING, A
$        STRING INDICATING DESVAR ID NUMBERS, A DESVAR ID, A STRING
$        INDICATING THAT THE LABELS FOR THE CONSTANTS IN A DTABLE ENTRY
$        FOLLOW, THE LABELS OF CONSTANTS IN THE DTABLE INPUT,
$        A STRING INDICATING DRESP1 ID NUMBERS, DRESP1 IDS, A STRING
$        SIGNIFYING THAT THE IDS AND DIRECTIONS FOLLOWING ARE NODE
$        NUMBERS AND CARTESIAN DIRECTION COMPONENTS, NODE NUMBERS,
$        AND CARTESIAN DIRECTIONS.
$
$DRESP2 ID      LABEL   EQID    REGION  XXXX    XXXX    XXXX    XXXX
DRESP2  5       RHSTWIST5                                               +DR25
$       DRESP1  NR1     NR2     NR3     ETC
+DR25   DRESP1  101     100
$
DRESP2  6       LHSTWIST5                                               +DR26
+DR26   DRESP1  201     100
$
$ EQUATION DEFINING SECOND LEVEL RESPONSE FOR TIP TWIST
$
$        THE DEQATN ENTRY DEFINES THE EQUATION(S) USED IN THE DESIGN
$        PROCESS.  IT LISTS A UNIQUE EQUATION ID, AND THE EQUATION IS
$        WRITTEN IN FORTRAN LIKE SYNTAX FOLLOWING THE RULES IN DEFINING
$        DMAP ASSIGNMENTS AND FUNCTIONS.
$
$DEQATN EQID            EQUATION
DEQATN  5       F(RTIP,RROOT) = RTIP - RROOT
$
$
$ TIP TWIST CONSTRAINTS
$
DCONSTR 50      5       -0.017450.01745
DCONSTR 50      6       -0.017450.01745
DCONSTR 60      5       -.008726 .008726
DCONSTR 60      6       -.008726 .008726
DCONADD 1       50      200
DCONADD 2       60      200
$
$                       *       *       *
$
$                 * AILERON ROLL EFFECTIVENESS *
$
$
$ RESPONSES REQUIRED FOR ROLL EFFECTIVENESS
$
DRESP1  1401    CLDELTA STABDER                 517     0       4
DRESP1  1402    CLP     STABDER                 513     0       4
$
$
$DRESP2 ID      LABEL   EQID    REGION  XXX     XXX     XXX     XXX     +DRES2
DRESP2  2401    ROLLEFF 103                                             +DR2401
$       DRESP1  NR1     NR2     NR3     ETC
+DR2401 DRESP1  1402    1401
```

Listing 10-1 Input File for Design Sensitivities of FSW Airplane (Continued)

```
$DEQATN EQID            EQUATION
DEQATN  103     F(A,B) = -B/A
$
$ SUBSONIC AILERON EFFECTIVENESS CONSTRAINT
$
DCONSTR 50      2401    0.60
$
$ SUBSONIC AILERON EFFECTIVENESS CONSTRAINT
$
DCONSTR 60      2401    0.43
$
$                       *       *       *
$
$                 * SUBSONIC AND SUPERSONIC FLUTTER *
$
$ RESPONSE FOR SUBSONIC FLUTTER
$
$DRESP1 ID      LABEL   FLUTTER XXXX    REGION  SID     XXXX    ID_MODE +DR
DRESP1  1       FLUTTER FLUTTER                                 88      +DR1
$       ID_DENS ID_MACH ID_VEL
+DR1    1       2       4
$
$ SELECTION OF FLUTTER MODES FOR OPTIMIZATION
$
SET1    88      4       THRU    7
$
$ SELECTION OF VELOCITIES FOR IMPOSING FLUTTER CONSTRAINTS
$
FLFACT  4       1000.0  1300.0  1500.0
$
$ EQUATION FOR SECOND LEVEL FLUTTER RESPONSE TO CONSTRAIN SYSTEM DAMPING
$
DRESP2  4       GDAMP   4                                               +DR24
+DR24   DRESP1  1
DEQATN  4       F(A) = (A - 0.03)/0.1
$
$ CONSTRAINT ON AEROELASTIC SYSTEM DAMPING
$
DCONSTR 6       4       -1.0+20 -0.3
$
$
$ RESPONSE FOR SUPERSONIC FLUTTER
$
$DRESP1 ID      LABEL   FLUTTER XXXX    REGION  SID     XXXX    ID_MODE +DR
DRESP1  11      FLUTTER FLUTTER                                 89      +DR11
$       ID_DENS ID_MACH ID_VEL
+DR11   11      12      14
$
SET1    89      4       THRU    7
$
FLFACT  14      1000.0  1300.0  1500.0
$
DRESP2  21      GDAMP   4                                               +DR21
+DR21   DRESP1  11
$
DCONSTR 7       21      -1.0+20 -0.3
$
$                       *       *       *
$
$                * OPTIMIZATION CONTROL PARAMS *
$
$        THE DOPTPRM ENTRY IS USED TO OVERRIDE DEFAULT OPTIMIZATION
$        PARAMETERS.  THE DOPTPRM ENTRY IS USED
$        HERE TO SET THE MAXIMUM NUMBER OF DESIGN CYCLES TO 25 AND TO
$        REQUEST DETAILED RESULTS FOLLOWING EACH OPTIMIZATION CYCLE.
$
$       PARAM1  VAL1    PARAM2  VAL2    ETC
DOPTPRM DESMAX  25      P1      2       P2      15      DELB    0.01
$
$        THE PARAMETER CDIF,YES FORCES THE SELECTION OF THE CENTRAL
```

Listing 10-1 Input File for Design Sensitivities of FSW Airplane (Continued)

```
$        DIFFERENCE SCHEME USED IN THE SEMI-ANALYTIC APPROACH
$        REGARDLESS OF THE TYPE OF OPTIMIZATION REQUESTED.
PARAM   CDIF    YES
$
$        THE BULK DATA PARAMETER, NASPRT, IS USED TO SPECIFY HOW OFTEN
$        MSC/NASTRAN OUTPUT IS TO BE PROVIDED.  ITS VALUE INDICATES THAT
$        OUTPUT IS TO BE COMPUTED EVERY N-TH DESIGN CYCLE.
PARAM   NASPRT  2
$
$        THE DSCREEN ENTRY IS USED HERE TO FORCE RETENTION OF ALL THE
$        CONSTRAINTS SO THAT THE DESIRED RESPONSE SENSITIVITIES WILL
$        BE PRINTED.  CONSTRAINTS ARE RETAINED IF THEY ARE GREATER
$        THAN TRS.
$SCREEN RTYPE   TRS     NSTR
DSCREEN STRESS  -2.0
DSCREEN EQUA    -2.0
AELIST  1000    1000    THRU    1007
AELIST  1100    1119    1123    1127    1131
AELIST  2000    2000    THRU    2007
AELIST  2100    2103    2107    2111    2115
AELIST  3000    3103    3107    3111    3115
AERO    1               10.     .002378
AEROS   1       100     10.     40.     400.
AESTAT  501     ANGLEA
AESTAT  502     PITCH
AESTAT  503     URDD3
AESTAT  504     URDD5
AESTAT  511     SIDES
AESTAT  512     YAW
AESTAT  513     ROLL
AESTAT  514     URDD2
AESTAT  515     URDD4
AESTAT  516     URDD6
AESURF  505     ELEV    1       1000    1       2000
AESURF  517     AILERON 110     1100    210     2100
AESURF  518     RUDDER  301     3000
CAERO1  1000    1000            2       4                       1       +
+       10.     0.      0.      10.     10.     5.      0.      10.
CAERO1  1100    1000            8       4                       1       +
+       25.     0.      0.      10.     13.4529920.     0.      10.
CAERO1  2000    1000            2       4                       1       +
+       10.     -5.     0.      10.     10.     0.      0.      10.
CAERO1  2100    1000            8       4                       1       +
+       13.45299-20.    0.      10.     25.     0.      0.      10.
CAERO1  3100    1000            4       4                       1       +
+       30.7735 0.      10.     10.     25.     0.      0.      10.
CBAR    101     100     97      98      0.      0.      1.
CBAR    102     100     98      90      0.      0.      1.
CBAR    103     100     90      99      0.      0.      1.
CBAR    104     100     99      100     0.      0.      1.
CBAR    110     101     100     110     0.      0.      1.
CBAR    120     102     110     120     0.      0.      1.
CBAR    210     101     100     210     0.      0.      1.
CBAR    220     102     210     220     0.      0.      1.
CBAR    310     103     100     310     0.      0.      1.
CONM2   97      97      0       3000.
CONM2   98      98      0       3000.
CONM2   99      99      0       3000.
CONM2   100     100     0       3000.
CONM2   111     111     0       300.
CONM2   112     112     0       200.
CONM2   121     121     0       300.
CONM2   122     122     0       200.
CONM2   211     211     0       300.
CONM2   212     212     0       200.
CONM2   221     221     0       300.
CONM2   222     222     0       200.
CONM2   311     311     0       30.
CONM2   312     312     0       20.
CORD2R  1       0       12.5    0.      0.      12.5    0.      10.     +
+       20.     0.      0.
```

Listing 10-1 Input File for Design Sensitivities of FSW Airplane (Continued)

```
CORD2R  2       0       30.     0.      0.      30.     0.      10.     +
+       38.660255.      0.
CORD2R  20      0       30.     0.      0.      30.     0.      10.     +
+       38.66025-5.     0.
CORD2R  100     0       15.     0.      0.      15.     0.      -10.    +
+       0.      0.      0.
CORD2R  110     0       26.7265 10.     0.      26.7265 10.     -10.    +
+       36.7265 15.7735 0.
CORD2R  210     0       26.7265 -10.    0.      26.7265 -10.    10.     +
+       36.7265 -15.77350.
CORD2R  300     0       30.     0.      0.      30.     10.     0.      +
+       20.     0.      5.7735
CORD2R  301     0       32.5    0.      0.      32.5    -10.    0.      +
+       22.5    0.      5.7735
DCONADD 1       50      200
DCONADD 2       60      200
DCONSTR 6       4       -1E+20  -.3
DCONSTR 7       21      -1E+20  -.3
DCONSTR 50      5       -.01745 .01745
DCONSTR 50      6       -.01745 .01745
DCONSTR 50      2401    .6
DCONSTR 60      5       -.008726.008726
DCONSTR 60      6       -.008726.008726
DCONSTR 60      2401    .43
DCONSTR 200     1001    -5.760+67200000.
DCONSTR 200     1002    -5.760+67200000.
DEQATN  4       F(A) = (A - 0.03)/0.1
DEQATN  5       F(RTIP,RROOT) = RTIP - RROOT
DEQATN  103     F(A,B) = -B/A
DESVAR  10      PBAR101 1.      .001    100.
DESVAR  20      PBAR102 1.      .001    100.
DESVAR  30      PBAR103 .1      .001    100.
DOPTPRM DELB    .01     DESMAX  25      P1      2       P2      15
DRESP1  1       FLUTTER FLUTTER                         88      +
+       1       2       4
DRESP1  10      WEIGHT  WEIGHT
DRESP1  11      FLUTTER FLUTTER                         89      +
+       11      12      14
DRESP1  100     RTROT   DISP            5               100
DRESP1  101     RTIPROT DISP            5               120
DRESP1  201     LTIPROT DISP            5               220
DRESP1  1001    TEN110  STRESS  PBAR            7               101     +
+       102     103
DRESP1  1002    COM110  STRESS  PBAR            8               101     +
+       102     103
DRESP1  1401    CLDELTA STABDER                 517     0       4
DRESP1  1402    CLP     STABDER                 513     0       4
DRESP2  4       GDAMP   4                                               +
+       DRESP1  1
DRESP2  5       RHSTWIST5                                               +
+       DRESP1  101     100
DRESP2  6       LHSTWIST5                                               +
+       DRESP1  201     100
DRESP2  21      GDAMP   4                                               +
+       DRESP1  11
DRESP2  2401    ROLLEFF 103                                             +
+       DRESP1  1402    1401
DSCREEN EQUA    -2.
DSCREEN STRESS  -2.
DVPREL1 1014    PBAR    101     4                                       +
+       10      1.5
DVPREL1 1015    PBAR    101     5                                       +
+       10      .173611
DVPREL1 1016    PBAR    101     6                                       +
+       10      2.
DVPREL1 1017    PBAR    101     7                                       +
+       10      .462963
DVPREL1 1024    PBAR    102     4                                       +
+       20      1.5
DVPREL1 1025    PBAR    102     5                                       +
```

Listing 10-1 Input File for Design Sensitivities of FSW Airplane (Continued)

```
+       20      .173611
DVPREL1 1026    PBAR    102     6                                       +
+       20      2.
DVPREL1 1027    PBAR    102     7                                       +
+       20      .462963
DVPREL1 1028    PBAR    103     4                                       +
+       30      1.5
DVPREL1 1029    PBAR    103     5                                       +
+       30      .173611
DVPREL1 1030    PBAR    103     6                                       +
+       30      2.
DVPREL1 1031    PBAR    103     7                                       +
+       30      .462963
EIGR    20      AGIV                    15                      +
+       MAX
FLFACT  1       1.
FLFACT  2       .9
FLFACT  3       1000.   1100.   1200.   1300.   1400.   1500.   1600.
FLFACT  4       1000.   1300.   1500.
FLFACT  11      1.
FLFACT  12      1.2
FLFACT  13      1000.   1100.   1200.   1300.   1400.   1500.   1600.
FLFACT  14      1000.   1300.   1500.
FLUTTER 30      PK      1       2       3       S       8
FLUTTER 40      PK      11      12      13      S       8
GRID    90              15.     0.      0.
GRID    97              0.      0.      0.
GRID    98              10.     0.      0.
GRID    99              20.     0.      0.
GRID    100             30.     0.      0.
GRID    110             27.113255.      0.
GRID    111             24.613255.      0.
GRID    112             29.613255.      0.
GRID    120             21.3397515.     0.
GRID    121             18.8397515.     0.
GRID    122             23.8397515.     0.
GRID    210             27.11325-5.     0.
GRID    211             24.61325-5.     0.
GRID    212             29.61325-5.     0.
GRID    220             21.33975-15.    0.
GRID    221             18.83975-15.    0.
GRID    222             23.83975-15.    0.
GRID    310             32.886750.      5.
GRID    311             30.386750.      5.
GRID    312             35.386750.      5.
MAT1    1       1.44E+095.4E+08         0.
MAT1    2       1.44E+095.4E+08         38.49002                        +
+       7200000.5760000.
MAT1    3       1.44E+095.4E+08         5.773503                        +
+       7200000.5760000.
MKAERO1 .9      1.2                                                     +
+       .001    .01     .1      .3      .5      1.
OMIT1   4       110     120     210     220     310
PAERO1  1000
PARAM   AUNITS  .031081
PARAM   CDIF    YES
PARAM   GRDPNT  90
PARAM   LMODES  12
PARAM   NASPRT  2
PARAM   OPPHIPA 1
PARAM   WTMASS  .031081
PBAR    100     1       4.      .347222 .3      1.                      +
+       1.      1.      1.      -1.     -1.     1.      -1.     -1.     +
+                       0.
PBAR    101     2       1.5     .173611 2.      .462963                 +
+       .5      3.      .5      -3.     -.5     3.      -.5     -3.     +
+                       0.
PBAR    102     2       1.5     .173611 2.      .462963                 +
+       .5      3.      .5      -3.     -.5     3.      -.5     -3.     +
+                       0.
```

Listing 10-1 Input File for Design Sensitivities of FSW Airplane (Continued)

```
PBAR    103     3       1.5     .173611 2.      .462963                 +
+       .5      3.      .5      -3.     -.5     3.      -.5     -3.     +
+                       0.
RBAR    111     110     111     123456
RBAR    112     110     112     123456
RBAR    121     120     121     123456
RBAR    122     120     122     123456
RBAR    211     210     211     123456
RBAR    212     210     212     123456
RBAR    221     220     221     123456
RBAR    222     220     222     123456
RBAR    311     310     311     123456
RBAR    312     310     312     123456
SET1    88      4       5       6       7
SET1    89      4       5       6       7
SET1    1000    98      99
SET1    1100    99      100     111     112     121     122
SET1    2100    99      100     211     212     221     222
SET1    3100    99      100     311     312
SPC1    1       1       90
SPLINE2 1501    1000    1000    1007    1000    0.      1.      1       +
+       1.      -1.
SPLINE2 1601    1100    1100    1131    1100    0.      1.      2       +
+       -1.     -1.
SPLINE2 2501    2000    2000    2007    1000    0.      1.      1       +
+       1.      -1.
SPLINE2 2601    2100    2100    2131    2100    0.      1.      20      +
+       -1.     -1.
SPLINE2 3100    3100    3100    3115    3100    0.      1.      300     +
+       -1.     -1.
SUPORT  90      23456
TRIM    1       .9      1200.   PITCH   0.      URDD3   -6.             +
+       URDD5   0.      AILERON 0.      RUDDER  0.      URDD2   0.      +
+       URDD4   0.      URDD6   0.
TRIM    2       1.2     863.    PITCH   0.      URDD3   -4.             +
+       URDD5   0.      AILERON 0.      RUDDER  0.      URDD2   0.      +
+       URDD4   0.      URDD6   0.
TRIM    3       .9      1200.   PITCH   6.0499-4URDD3   -4.8            +
+       URDD5   0.      AILERON .174533 YAW     0.      URDD2   0.      +
+       URDD4   0.      URDD6   0.
TRIM    4       .9      1200.   PITCH   6.0499-4URDD3   -4.8            +
+       URDD5   0.      AILERON .174533 ROLL    0.      YAW     0.      +
+       URDD2   0.      URDD6   0.
TRIM    5       .45     300.    ANGLEA  .0031512ELEV    .174533         +
+       PITCH   0.      SIDES   0.      ROLL    0.      YAW     0.      +
+       AILERON 0.      RUDDER  .174533
ENDDATA
```

Listing 10-2 Output for Design Sensitivities of FSW Airplane

```
 -----   COMPARISON BETWEEN INPUT PROPERTY VALUES FROM ANALYSIS AND DESIGN MODELS -----

     ---------------------------------------------------------------------------------------------------------------------------
       PROPERTY   PROPERTY   PROPERTY     ANALYSIS         DESIGN           LOWER            UPPER          DIFFERENCE     SPAWNING
         TYPE        ID        NAME         VALUE           VALUE           BOUND            BOUND             FLAG           FLAG
     ---------------------------------------------------------------------------------------------------------------------------
       PBAR          101          A    1.500000E+00    1.500000E+00        N/A              N/A              NONE
       PBAR          101         I1    1.736110E-01    1.736110E-01        N/A              N/A              NONE
       PBAR          101         I2    2.000000E+00    2.000000E+00        N/A              N/A              NONE
       PBAR          101          J    4.629630E-01    4.629630E-01        N/A              N/A              NONE
       PBAR          102          A    1.500000E+00    1.500000E+00        N/A              N/A              NONE
       PBAR          102         I1    1.736110E-01    1.736110E-01        N/A              N/A              NONE
       PBAR          102         I2    2.000000E+00    2.000000E+00        N/A              N/A              NONE
       PBAR          102          J    4.629630E-01    4.629630E-01        N/A              N/A              NONE
       PBAR          103          A    1.500000E+00    1.500000E-01        N/A              N/A           WARNING
       PBAR          103         I1    1.736110E-01    1.736110E-02        N/A              N/A           WARNING
       PBAR          103         I2    2.000000E+00    2.000000E-01        N/A              N/A           WARNING
       PBAR          103          J    4.629630E-01    4.629630E-02        N/A              N/A           WARNING

1    EXAMPLE HA200A: 30 DEG FWD SWEPT WING WITH CANARD AND  HA200A           JULY   9, 2019  MSC Nastran  7/ 8/19    PAGE   125
      DEMONSTRATION OF AEROELASTIC SENSITIVITY ANALYSIS
0     SUBSONIC FLUTTER ANALYSIS                                                                                SUBCASE 6
0                                                      FLUTTER  SUMMARY
                          CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = ASYMMETRIC
        POINT =     1     MACH NUMBER =  0.9000     DENSITY RATIO =  1.0000E+00     METHOD = PK


        KFREQ          1./KFREQ        VELOCITY           DAMPING         FREQUENCY             COMPLEX   EIGENVALUE
         0.0000      1.0000000E+25    1.0000000E+03   -6.3623685E-09     0.0000000E+00    -4.4100121E-07     0.0000000E+00
         0.0000      1.0000000E+25    1.1000000E+03   -7.4139958E-09     0.0000000E+00    -5.6528308E-07     0.0000000E+00
         0.0000      1.0000000E+25    1.2000000E+03   -8.5668987E-09     0.0000000E+00    -7.1256722E-07     0.0000000E+00
         0.0000      1.0000000E+25    1.3000000E+03   -9.8214687E-09     0.0000000E+00    -8.8499487E-07     0.0000000E+00
         0.0000      1.0000000E+25    1.4000000E+03   -1.1177954E-08     0.0000000E+00    -1.0847042E-06     0.0000000E+00
         0.0000      1.0000000E+25    1.5000000E+03   -1.2636808E-08     0.0000000E+00    -1.3138616E-06     0.0000000E+00
         0.0000      1.0000000E+25    1.6000000E+03   -1.4198424E-08     0.0000000E+00    -1.5746393E-06     0.0000000E+00
0                                                      FLUTTER  SUMMARY
                          CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = ASYMMETRIC
        POINT =     2     MACH NUMBER =  0.9000     DENSITY RATIO =  1.0000E+00     METHOD = PK


        KFREQ          1./KFREQ        VELOCITY           DAMPING         FREQUENCY             COMPLEX   EIGENVALUE
         0.0000      1.0000000E+25    1.0000000E+03    8.4468358E-06     0.0000000E+00     5.8548398E-04     0.0000000E+00
         0.0000      1.0000000E+25    1.1000000E+03    8.4527612E-06     0.0000000E+00     6.4448416E-04     0.0000000E+00
         0.0000      1.0000000E+25    1.2000000E+03    8.4592354E-06     0.0000000E+00     7.0361213E-04     0.0000000E+00
         0.0000      1.0000000E+25    1.3000000E+03    8.4663168E-06     0.0000000E+00     7.6288457E-04     0.0000000E+00
         0.0000      1.0000000E+25    1.4000000E+03    8.4739224E-06     0.0000000E+00     8.2230604E-04     0.0000000E+00
         0.0000      1.0000000E+25    1.5000000E+03    8.4819827E-06     0.0000000E+00     8.8188022E-04     0.0000000E+00
         0.0000      1.0000000E+25    1.6000000E+03    8.4911657E-06     0.0000000E+00     9.4169066E-04     0.0000000E+00
0                                                      FLUTTER  SUMMARY
                          CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = ASYMMETRIC
        POINT =     3     MACH NUMBER =  0.9000     DENSITY RATIO =  1.0000E+00     METHOD = PK


        KFREQ          1./KFREQ        VELOCITY           DAMPING         FREQUENCY             COMPLEX   EIGENVALUE
         0.0000      1.0000000E+25    1.0000000E+03    5.9910422E-04     2.0126209E-03     3.7880372E-06     1.2645670E-02
         0.0000      1.0000000E+25    1.1000000E+03    5.7782717E-04     2.1881753E-03     3.9721894E-06     1.3748711E-02
         0.0000      1.0000000E+25    1.2000000E+03    5.5501140E-04     2.3564305E-03     4.1087187E-06     1.4805889E-02
         0.0000      1.0000000E+25    1.3000000E+03    5.3077153E-04     2.5167290E-03     4.1965649E-06     1.5813075E-02
         0.0000      1.0000000E+25    1.4000000E+03    5.0522512E-04     2.6684059E-03     4.2353246E-06     1.6766089E-02
         0.0000      1.0000000E+25    1.5000000E+03    4.7849129E-04     2.8107838E-03     4.2252397E-06     1.7660675E-02
         0.0000      1.0000000E+25    1.6000000E+03    4.5068959E-04     2.9431670E-03     4.1671804E-06     1.8492463E-02
0                                                      FLUTTER  SUMMARY
                          CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = ASYMMETRIC
        POINT =     4     MACH NUMBER =  0.9000     DENSITY RATIO =  1.0000E+00     METHOD = PK


        KFREQ          1./KFREQ        VELOCITY           DAMPING         FREQUENCY             COMPLEX   EIGENVALUE
         0.0378      2.6484189E+01    1.0000000E+03   -2.6558929E-01     1.2018865E+00    -1.0028221E+00     7.5516754E+00
         0.0378      2.6483660E+01    1.1000000E+03   -2.6536601E-01     1.3221015E+00    -1.1021989E+00     8.3070088E+00
         0.0378      2.6483134E+01    1.2000000E+03   -2.6512403E-01     1.4423212E+00    -1.2013262E+00     9.0623715E+00
         0.0378      2.6482627E+01    1.3000000E+03   -2.6486411E-01     1.5625446E+00    -1.3001857E+00     9.8177570E+00
         0.0378      2.6482160E+01    1.4000000E+03   -2.6458714E-01     1.6827700E+00    -1.3987605E+00     1.0573156E+01
         0.0378      2.6481755E+01    1.5000000E+03   -2.6429409E-01     1.8029954E+00    -1.4970350E+00     1.1328554E+01
         0.0378      2.6481438E+01    1.6000000E+03   -2.6398608E-01     1.9232181E+00    -1.5949954E+00     1.2083936E+01
```

Listing 10-2 Output for Design Sensitivities of FSW Airplane (Continued)

```
0                                                 FLUTTER  SUMMARY
                         CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = ASYMMETRIC
     POINT =     5      MACH NUMBER =  0.9000     DENSITY RATIO =  1.0000E+00     METHOD = PK

     KFREQ          1./KFREQ        VELOCITY           DAMPING          FREQUENCY           COMPLEX   EIGENVALUE
      0.0746       1.3409101E+01    1.0000000E+03    -6.5903945E-01     2.3738347E+00    -4.9148668E+00     1.4915243E+01
      0.0814       1.2283600E+01    1.1000000E+03    -6.3652940E-01     2.8504745E+00    -5.7001397E+00     1.7910059E+01
      0.0926       1.0796384E+01    1.2000000E+03    -5.8971104E-01     3.5379611E+00    -6.5545396E+00     2.2229665E+01
      0.1186       8.4333350E+00    1.3000000E+03    -3.3484398E-01     4.9067522E+00    -5.1616256E+00     3.0830033E+01
      0.1069       9.3564486E+00    1.4000000E+03    -1.5777949E+00     4.7628524E+00    -2.3608454E+01     2.9925884E+01
      0.0861       1.1615961E+01    1.5000000E+03    -2.3745274E+00     4.1104205E+00    -3.0662906E+01     2.5826533E+01
      0.0623       1.6040321E+01    1.6000000E+03    -3.6939773E+00     3.1750974E+00    -3.6846917E+01     1.9949726E+01
0                                                 FLUTTER  SUMMARY
                         CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = ASYMMETRIC
     POINT =     6      MACH NUMBER =  0.9000     DENSITY RATIO =  1.0000E+00     METHOD = PK

     KFREQ          1./KFREQ        VELOCITY           DAMPING          FREQUENCY           COMPLEX   EIGENVALUE
      0.2559       3.9084762E+00    1.0000000E+03    -1.3052097E-02     8.1440918E+00    -3.3394338E-01     5.1170838E+01
      0.2327       4.2964886E+00    1.1000000E+03    -1.4401516E-02     8.1494659E+00    -3.6871197E-01     5.1204604E+01
      0.2135       4.6836166E+00    1.2000000E+03    -1.5785278E-02     8.1554895E+00    -4.0443818E-01     5.1242452E+01
      0.1972       5.0697665E+00    1.3000000E+03    -1.7209242E-02     8.1621679E+00    -4.4128294E-01     5.1284413E+01
      0.1833       5.4548392E+00    1.4000000E+03    -1.8678768E-02     8.1695139E+00    -4.7939591E-01     5.1330569E+01
      0.1713       5.8387318E+00    1.5000000E+03    -2.0199383E-02     8.1775435E+00    -5.1893247E-01     5.1381021E+01
      0.1607       6.2213363E+00    1.6000000E+03    -2.1776856E-02     8.1862770E+00    -5.6005603E-01     5.1435895E+01
0                                                 FLUTTER  SUMMARY
                         CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = ASYMMETRIC
     POINT =     7      MACH NUMBER =  0.9000     DENSITY RATIO =  1.0000E+00     METHOD = PK

     KFREQ          1./KFREQ        VELOCITY           DAMPING          FREQUENCY           COMPLEX   EIGENVALUE
      0.2850       3.5088845E+00    1.0000000E+03    -2.0820399E-01     9.0715407E+00    -5.9336232E+00     5.6998171E+01
      0.2432       4.1113263E+00    1.1000000E+03    -2.6946305E-01     8.5164944E+00    -7.2095799E+00     5.3510713E+01
      0.2013       4.9675151E+00    1.2000000E+03    -3.5838804E-01     7.6893951E+00    -8.6575609E+00     4.8313894E+01
      0.1396       7.1633269E+00    1.3000000E+03    -6.4709565E-01     5.7766853E+00    -1.1743487E+01     3.6295984E+01
      0.1177       8.4986655E+00    1.4000000E+03     1.6736813E-01     5.2435743E+00     2.7570845E+00     3.2946349E+01
      0.1103       9.0680911E+00    1.5000000E+03     4.3815650E-01     5.2653290E+00     7.2477740E+00     3.3083038E+01
      0.1030       9.7113599E+00    1.6000000E+03     6.4964921E-01     5.2443306E+00     1.0703328E+01     3.2951101E+01
0                                                 FLUTTER  SUMMARY
                         CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = ASYMMETRIC
     POINT =     8      MACH NUMBER =  0.9000     DENSITY RATIO =  1.0000E+00     METHOD = PK

     KFREQ          1./KFREQ        VELOCITY           DAMPING          FREQUENCY           COMPLEX   EIGENVALUE
      0.5795       1.7257442E+00    1.0000000E+03    -3.1901385E-02     1.8444789E+01    -1.8485581E+00     1.1589203E+02
      0.5272       1.8967527E+00    1.1000000E+03    -3.4652796E-02     1.8460017E+01    -2.0096492E+00     1.1598771E+02
      0.4837       2.0672873E+00    1.2000000E+03    -3.7208406E-02     1.8476961E+01    -2.1598395E+00     1.1609417E+02
      0.4470       2.2373440E+00    1.3000000E+03    -3.9671445E-02     1.8495272E+01    -2.3050939E+00     1.1620922E+02
      0.4155       2.4069498E+00    1.4000000E+03    -4.2184302E-02     1.8514464E+01    -2.4536458E+00     1.1632981E+02
      0.3882       2.5761365E+00    1.5000000E+03    -4.4816115E-02     1.8534143E+01    -2.6094957E+00     1.1645345E+02
      0.3643       2.7449362E+00    1.6000000E+03    -4.7589467E-02     1.8554013E+01    -2.7739496E+00     1.1657830E+02

 ********************************************************************
                               *                                                                  *
                               *                                                                  *
                               *                D E S I G N    O P T I M I Z A T I O N            *
                               *                                                                  *
                               *                                                                  *
                               ********************************************************************


                                        ***********************************************
                                        *                                             *
                                        *       I N I T I A L    A N A L Y S I S      *
                                        *                                             *
                                        ***********************************************


                                    *******   ANALYSIS RESULTS BASED ON THE INITIAL DESIGN   *******

                                                -----   DESIGN OBJECTIVE   -----

    ----------------------------------------------------------------------------------------------------
               INTERNAL                                   MINIMIZE
               RESPONSE                        RESPONSE      OR       SUPERELEMENT     SUBCASE
                  ID          DRESPx             TYPE     MAXIMIZE          ID            ID             VALUE
    ----------------------------------------------------------------------------------------------------
                     1        DRESP1        WEIGHT        MINIMIZE              0             0        1.6055E+04
```

Listing 10-2 Output for Design Sensitivities of FSW Airplane (Continued)

----- DESIGN VARIABLES -----

INTERNAL ID	DESVAR ID	LABEL	LOWER BOUND	VALUE	UPPER BOUND
1	10	PBAR101	1.0000E-03	1.0000E+00	1.0000E+02
2	20	PBAR102	1.0000E-03	1.0000E+00	1.0000E+02
3	30	PBAR103	1.0000E-03	1.0000E-01	1.0000E+02

----- DESIGNED PROPERTIES -----

PROPERTY TYPE	PROPERTY ID	PROPERTY NAME	TYPE OF PROPERTY	LOWER BOUND	VALUE	UPPER BOUND
PBAR	101	A	DVPREL1	N/A	1.5000E+00	N/A
PBAR	101	I1	DVPREL1	N/A	1.7361E-01	N/A
PBAR	101	I2	DVPREL1	N/A	2.0000E+00	N/A
PBAR	101	J	DVPREL1	N/A	4.6296E-01	N/A
PBAR	102	A	DVPREL1	N/A	1.5000E+00	N/A
PBAR	102	I1	DVPREL1	N/A	1.7361E-01	N/A
PBAR	102	I2	DVPREL1	N/A	2.0000E+00	N/A
PBAR	102	J	DVPREL1	N/A	4.6296E-01	N/A
PBAR	103	A	DVPREL1	N/A	1.5000E-01	N/A
PBAR	103	I1	DVPREL1	N/A	1.7361E-02	N/A
PBAR	103	I2	DVPREL1	N/A	2.0000E-01	N/A
PBAR	103	J	DVPREL1	N/A	4.6296E-02	N/A

----- DESIGN CONSTRAINTS ON RESPONSES -----

(MAXIMUM RESPONSE CONSTRAINTS MARKED WITH **)

INTERNAL ID	DCONSTR ID	INTERNAL RESPONSE ID	EXTERNAL DRESPx ID	RESPONSE TYPE	L/U FLAG	INTERNAL REGION ID	SUBCASE ID	VALUE
1	50	1	5	EQUA	LOWER	5	1	-1.6046E+00
2	50	1	5	EQUA	UPPER	5	1	-3.9543E-01
3	50	2	6	EQUA	LOWER	6	1	-1.6046E+00
4	50	2	6	EQUA	UPPER	6	1	-3.9543E-01
5	50	3	2401	EQUA	LOWER	2401	1	1.7847E-02
6	50	3	2401	EQUA	UPPER	2401	1	-1.0000E+00
7	200	5	1001	STRESS	LOWER	16	1	-1.1965E+00
8	200	5	1001	STRESS	UPPER	16	1	-8.4277E-01
9	200	6	1001	STRESS	LOWER	16	1	-1.1965E+00
10	200	6	1001	STRESS	UPPER	16	1	-8.4277E-01
11	200	7	1001	STRESS	LOWER	17	1	-1.1049E+00
12	200	7	1001	STRESS	UPPER	17	1	-9.1609E-01
13	200	8	1001	STRESS	LOWER	17	1	-1.1049E+00
14	200	8	1001	STRESS	UPPER	17	1	-9.1609E-01
15	200	9	1001	STRESS	LOWER	18	1	-1.0035E+00
16	200	9	1001	STRESS	UPPER	18	1	-9.9722E-01
17	200	10	1002	STRESS	LOWER	16	1	-8.0347E-01
18	200	10	1002	STRESS	UPPER	16	1	-1.1572E+00
19	200	11	1002	STRESS	LOWER	16	1	-8.0347E-01
20	200	11	1002	STRESS	UPPER	16	1	-1.1572E+00
21	200	12	1002	STRESS	LOWER	17	1	-8.9511E-01
22	200	12	1002	STRESS	UPPER	17	1	-1.0839E+00
23	200	13	1002	STRESS	LOWER	17	1	-8.9511E-01
24	200	13	1002	STRESS	UPPER	17	1	-1.0839E+00
25	200	14	1002	STRESS	LOWER	18	1	-9.9589E-01
26	200	14	1002	STRESS	UPPER	18	1	-1.0033E+00
27	60	4	5	EQUA	LOWER	5	2	-1.4930E+00
28	60	4	5	EQUA	UPPER	5	2	-5.0701E-01
29	60	5	6	EQUA	LOWER	6	2	-1.4930E+00
30	60	5	6	EQUA	UPPER	6	2	-5.0701E-01
31	60	6	2401	EQUA	LOWER	2401	2	1.1240E-02
32	60	6	2401	EQUA	UPPER	2401	2	-1.0000E+00
33	200	20	1001	STRESS	LOWER	16	2	-1.1107E+00
34	200	20	1001	STRESS	UPPER	16	2	-9.1142E-01
35	200	21	1001	STRESS	LOWER	16	2	-1.1107E+00
36	200	21	1001	STRESS	UPPER	16	2	-9.1142E-01
37	200	22	1001	STRESS	LOWER	17	2	-1.0540E+00
38	200	22	1001	STRESS	UPPER	17	2	-9.5682E-01
39	200	23	1001	STRESS	LOWER	17	2	-1.0540E+00
40	200	23	1001	STRESS	UPPER	17	2	-9.5682E-01
41	200	24	1001	STRESS	LOWER	18	2	-1.0023E+00
42	200	24	1001	STRESS	UPPER	18	2	-9.9814E-01
43	200	25	1002	STRESS	LOWER	16	2	-8.8928E-01
44	200	25	1002	STRESS	UPPER	16	2	-1.0886E+00
45	200	26	1002	STRESS	LOWER	16	2	-8.8928E-01

Listing 10-2 Output for Design Sensitivities of FSW Airplane (Continued)

```
 46        200        26       1002   STRESS     UPPER          16         2    -1.0886E+00
           47        200        27       1002   STRESS     LOWER          17         2    -9.4602E-01
           48        200        27       1002   STRESS     UPPER          17         2    -1.0432E+00
           49        200        28       1002   STRESS     LOWER          17         2    -9.4602E-01
           50        200        28       1002   STRESS     UPPER          17         2    -1.0432E+00
           51        200        29       1002   STRESS     LOWER          18         2    -9.9726E-01
           52        200        29       1002   STRESS     UPPER          18         2    -1.0022E+00
           53        200        32       1001   STRESS     LOWER          16         3    -1.1954E+00
           54        200        32       1001   STRESS     UPPER          16         3    -8.4365E-01
           55        200        33       1001   STRESS     LOWER          16         3    -1.1164E+00
           56        200        33       1001   STRESS     UPPER          16         3    -9.0692E-01
           57        200        34       1001   STRESS     LOWER          17         3    -1.1094E+00
           58        200        34       1001   STRESS     UPPER          17         3    -9.1249E-01
           59        200        35       1001   STRESS     LOWER          17         3    -1.0567E+00
           60        200        35       1001   STRESS     UPPER          17         3    -9.5465E-01
           61        200        36       1001   STRESS     LOWER          18         3    -1.0164E+00
           62        200        36       1001   STRESS     UPPER          18         3    -9.8691E-01
           63        200        37       1002   STRESS     LOWER          16         3    -8.0456E-01
           64        200        37       1002   STRESS     UPPER          16         3    -1.1564E+00
           65        200        38       1002   STRESS     LOWER          16         3    -8.8365E-01
           66        200        38       1002   STRESS     UPPER          16         3    -1.0931E+00
           67        200        39       1002   STRESS     LOWER          17         3    -8.9061E-01
           68        200        39       1002   STRESS     UPPER          17         3    -1.0875E+00
           69        200        40       1002   STRESS     LOWER          17         3    -9.4331E-01
           70        200        40       1002   STRESS     UPPER          17         3    -1.0454E+00
           71        200        41       1002   STRESS     LOWER          18         3    -9.8314E-01
           72        200        41       1002   STRESS     UPPER          18         3    -1.0135E+00
           73        200        42       1001   STRESS     LOWER          16         4    -1.1719E+00
           74        200        42       1001   STRESS     UPPER          16         4    -8.6247E-01
           75        200        43       1001   STRESS     LOWER          16         4    -1.1399E+00
           76        200        43       1001   STRESS     UPPER          16         4    -8.8810E-01
           77        200        44       1001   STRESS     LOWER          17         4    -1.0961E+00
           78        200        44       1001   STRESS     UPPER          17         4    -9.2313E-01
           79        200        45       1001   STRESS     LOWER          17         4    -1.0700E+00
           80        200        45       1001   STRESS     UPPER          17         4    -9.4401E-01
           81        200        46       1001   STRESS     LOWER          18         4    -1.0064E+00
           82        200        46       1001   STRESS     UPPER          18         4    -9.9491E-01
           83        200        47       1002   STRESS     LOWER          16         4    -8.2809E-01
           84        200        47       1002   STRESS     UPPER          16         4    -1.1375E+00
           85        200        48       1002   STRESS     LOWER          16         4    -8.6012E-01
           86        200        48       1002   STRESS     UPPER          16         4    -1.1119E+00
           87        200        49       1002   STRESS     LOWER          17         4    -9.0391E-01
           88        200        49       1002   STRESS     UPPER          17         4    -1.0769E+00
           89        200        50       1002   STRESS     LOWER          17         4    -9.3001E-01
           90        200        50       1002   STRESS     UPPER          17         4    -1.0560E+00
           91        200        51       1002   STRESS     LOWER          18         4    -9.9313E-01
           92        200        51       1002   STRESS     UPPER          18         4    -1.0055E+00
           93        200        52       1001   STRESS     LOWER          16         5    -1.0211E+00
           94        200        52       1001   STRESS     UPPER          16         5    -9.8310E-01
           95        200        53       1001   STRESS     LOWER          16         5    -1.0041E+00
           96        200        53       1001   STRESS     UPPER          16         5    -9.9676E-01
           97        200        54       1001   STRESS     LOWER          17         5    -1.0129E+00
           98        200        54       1001   STRESS     UPPER          17         5    -9.8970E-01
           99        200        55       1001   STRESS     LOWER          17         5    -1.0040E+00
          100        200        55       1001   STRESS     UPPER          17         5    -9.9680E-01
          101        200        56       1001   STRESS     LOWER          18         5    -1.1010E+00
          102        200        56       1001   STRESS     UPPER          18         5    -9.1923E-01
          103        200        57       1002   STRESS     LOWER          16         5    -9.7853E-01
          104        200        57       1002   STRESS     UPPER          16         5    -1.0172E+00
          105        200        58       1002   STRESS     LOWER          16         5    -9.9629E-01
          106        200        58       1002   STRESS     UPPER          16         5    -1.0030E+00
          107        200        59       1002   STRESS     LOWER          17         5    -9.8696E-01
          108        200        59       1002   STRESS     UPPER          17         5    -1.0104E+00
          109        200        60       1002   STRESS     LOWER          17         5    -9.9615E-01
          110        200        60       1002   STRESS     UPPER          17         5    -1.0031E+00
          111        200        61       1002   STRESS     LOWER          18         5    -8.9905E-01
          112        200        61       1002   STRESS     UPPER          18         5    -1.0808E+00
          113          6         7          4       EQUA   LOWER           4         6    -1.0000E+00
          114          6         8          4       EQUA   LOWER           4         6    -1.0000E+00
          115          6         9          4       EQUA   LOWER           4         6    -1.0000E+00
          116          6        10          4       EQUA   LOWER           4         6    -1.0000E+00
          117          6        11          4       EQUA   LOWER           4         6    -1.0000E+00
          118          6        12          4       EQUA   LOWER           4         6    -1.0000E+00
          119          6        13          4       EQUA   LOWER           4         6    -1.0000E+00
          120          6        13          4       EQUA   UPPER           4         6    -4.3507E-01
          121          6        14          4       EQUA   LOWER           4         6    -1.0000E+00
          122          6        14          4       EQUA   UPPER           4         6    -5.7364E-01
          123          6        15          4       EQUA   LOWER           4         6    -1.0000E+00
          124          6        15          4       EQUA   UPPER           4         6    -6.7331E-01
          125          6        16          4       EQUA   LOWER           4         6    -1.0000E+00
          126          6        17          4       EQUA   LOWER           4         6    -1.0000E+00
          127          6        18          4       EQUA   LOWER           4         6    -1.0000E+00
          128          6        18          4       EQUA   UPPER           4         6     1.4605E+01**
```

Listing 10-2 Output for Design Sensitivities of FSW Airplane (Continued)

```
         129          7          19          21        EQUA   LOWER          21          7    -1.0000E+00
         130          7          20          21        EQUA   LOWER          21          7    -1.0000E+00
         131          7          21          21        EQUA   LOWER          21          7    -1.0000E+00
         132          7          22          21        EQUA   LOWER          21          7    -1.0000E+00
         133          7          23          21        EQUA   LOWER          21          7    -1.0000E+00
         134          7          24          21        EQUA   LOWER          21          7    -1.0000E+00
         135          7          24          21        EQUA   UPPER          21          7     8.1234E+00
         136          7          25          21        EQUA   LOWER          21          7    -1.0000E+00
         137          7          25          21        EQUA   UPPER          21          7    -4.7432E-01
         138          7          26          21        EQUA   LOWER          21          7    -1.0000E+00
         139          7          26          21        EQUA   UPPER          21          7    -7.1870E-01
         140          7          27          21        EQUA   LOWER          21          7    -1.0000E+00
         141          7          27          21        EQUA   UPPER          21          7    -8.6875E-01
         142          7          28          21        EQUA   LOWER          21          7    -1.0000E+00
         143          7          29          21        EQUA   LOWER          21          7    -1.0000E+00
         144          7          30          21        EQUA   LOWER          21          7    -1.0000E+00


                          ----------------------------------------------------------------------
                          |       R E S P O N S E S     I N     D E S I G N     M O D E L        |
                          ----------------------------------------------------------------------

                                         (N/A - BOUND NOT ACTIVE OR AVAILABLE)
                                       (*** VIOLATED RESPONSES MARKED WITH V ***)
                                       (*** ACTIVE RESPONSES MARKED WITH A ***)

                                            -----    WEIGHT RESPONSE    -----

 ---------------------------------------------------------------------------------------------------------------
      INTERNAL     DRESP1     RESPONSE      ROW        COLUMN         LOWER                          UPPER
         ID          ID         LABEL        ID          ID           BOUND          VALUE           BOUND
 ---------------------------------------------------------------------------------------------------------------
           1         10       WEIGHT         3           3             N/A         1.6055E+04        N/A

                              I N I T I A L   A N A L Y S I S   S U B C A S E =       1

                                        -----    DISPLACEMENT RESPONSES    -----

 ---------------------------------------------------------------------------------------------------------------
      INTERNAL     DRESP1     RESPONSE      GRID     COMPONENT        LOWER                          UPPER
         ID          ID         LABEL        ID         NO.           BOUND          VALUE           BOUND
 ---------------------------------------------------------------------------------------------------------------
             2        100     RTROT          100          5            N/A         1.1291E-02         N/A
             3        101     RTIPROT        120          5            N/A         2.1841E-02         N/A
             4        201     LTIPROT        220          5            N/A         2.1841E-02         N/A

                                           -----    STRESS RESPONSES    -----

 --------------------------------------------------------------------------------------------------------------
    INTERNAL     DRESP1     RESPONSE     ELEMENT     VIEW     COMPONENT        LOWER                         UPPER
       ID          ID         LABEL         ID      ELM ID       NO.           BOUND          VALUE          BOUND
 --------------------------------------------------------------------------------------------------------------
           5        1001    TEN110         110                      7    -5.7600E+06      1.1320E+06    7.2000E+06
           6        1001    TEN110         210                      7    -5.7600E+06      1.1320E+06    7.2000E+06
           7        1001    TEN110         120                      7    -5.7600E+06      6.0417E+05    7.2000E+06
           8        1001    TEN110         220                      7    -5.7600E+06      6.0417E+05    7.2000E+06
           9        1001    TEN110         310                      7    -5.7600E+06      2.0050E+04    7.2000E+06
          10        1002    COM110         110                      8    -5.7600E+06     -1.1320E+06    7.2000E+06
          11        1002    COM110         210                      8    -5.7600E+06     -1.1320E+06    7.2000E+06
          12        1002    COM110         120                      8    -5.7600E+06     -6.0417E+05    7.2000E+06
          13        1002    COM110         220                      8    -5.7600E+06     -6.0417E+05    7.2000E+06
          14        1002    COM110         310                      8    -5.7600E+06     -2.3687E+04    7.2000E+06

                                     -----    STABILITY DERIVATIVE RESPONSES    -----

 ----------------------------------------------------------------------------------------------------------------
                                     RESTRAINED /               AESTAT /
  INTERNAL     DRESP1     RESPONSE   UNRESTRAINED   COMPONENT   AESURF        LOWER                          UPPER
     ID          ID         LABEL        FLAG          NO.        ID          BOUND          VALUE           BOUND
 ----------------------------------------------------------------------------------------------------------------
        15       1401    CLDELTA          0              4        517          N/A         2.6340E-01         N/A
        16       1402    CLP              0              4        513          N/A        -4.4697E-01         N/A

                              I N I T I A L   A N A L Y S I S   S U B C A S E =       2

                                        -----    DISPLACEMENT RESPONSES    -----

 ---------------------------------------------------------------------------------------------------------------
      INTERNAL     DRESP1     RESPONSE      GRID     COMPONENT        LOWER                          UPPER
         ID          ID         LABEL        ID         NO.           BOUND          VALUE           BOUND
 ---------------------------------------------------------------------------------------------------------------
            17        100     RTROT          100          5            N/A         5.9761E-03         N/A
            18        101     RTIPROT        120          5            N/A         1.0278E-02         N/A
            19        201     LTIPROT        220          5            N/A         1.0278E-02         N/A
```

Listing 10-2 Output for Design Sensitivities of FSW Airplane (Continued)

----- STRESS RESPONSES -----

INTERNAL ID	DRESP1 ID	RESPONSE LABEL	ELEMENT ID	VIEW ELM ID	COMPONENT NO.	LOWER BOUND	VALUE	UPPER BOUND
20	1001	TEN110	110		7	-5.7600E+06	6.3774E+05	7.2000E+06
21	1001	TEN110	210		7	-5.7600E+06	6.3774E+05	7.2000E+06
22	1001	TEN110	120		7	-5.7600E+06	3.1092E+05	7.2000E+06
23	1001	TEN110	220		7	-5.7600E+06	3.1092E+05	7.2000E+06
24	1001	TEN110	310		7	-5.7600E+06	1.3367E+04	7.2000E+06
25	1002	COM110	110		8	-5.7600E+06	-6.3774E+05	7.2000E+06
26	1002	COM110	210		8	-5.7600E+06	-6.3774E+05	7.2000E+06
27	1002	COM110	120		8	-5.7600E+06	-3.1092E+05	7.2000E+06
28	1002	COM110	220		8	-5.7600E+06	-3.1092E+05	7.2000E+06
29	1002	COM110	310		8	-5.7600E+06	-1.5792E+04	7.2000E+06

----- STABILITY DERIVATIVE RESPONSES -----

INTERNAL ID	DRESP1 ID	RESPONSE LABEL	RESTRAINED / UNRESTRAINED FLAG	COMPONENT NO.	AESTAT / AESURF ID	LOWER BOUND	VALUE	UPPER BOUND
30	1401	CLDELTA	0	4	517	N/A	2.1655E-01	N/A
31	1402	CLP	0	4	513	N/A	-5.0933E-01	N/A

I N I T I A L   A N A L Y S I S   S U B C A S E =   3

----- STRESS RESPONSES -----

INTERNAL ID	DRESP1 ID	RESPONSE LABEL	ELEMENT ID	VIEW ELM ID	COMPONENT NO.	LOWER BOUND	VALUE	UPPER BOUND
32	1001	TEN110	110		7	-5.7600E+06	1.1257E+06	7.2000E+06
33	1001	TEN110	210		7	-5.7600E+06	6.7018E+05	7.2000E+06
34	1001	TEN110	120		7	-5.7600E+06	6.3006E+05	7.2000E+06
35	1001	TEN110	220		7	-5.7600E+06	3.2654E+05	7.2000E+06
36	1001	TEN110	310		7	-5.7600E+06	9.4230E+04	7.2000E+06
37	1002	COM110	110		8	-5.7600E+06	-1.1257E+06	7.2000E+06
38	1002	COM110	210		8	-5.7600E+06	-6.7018E+05	7.2000E+06
39	1002	COM110	120		8	-5.7600E+06	-6.3006E+05	7.2000E+06
40	1002	COM110	220		8	-5.7600E+06	-3.2654E+05	7.2000E+06
41	1002	COM110	310		8	-5.7600E+06	-9.7140E+04	7.2000E+06

I N I T I A L   A N A L Y S I S   S U B C A S E =   4

----- STRESS RESPONSES -----

INTERNAL ID	DRESP1 ID	RESPONSE LABEL	ELEMENT ID	VIEW ELM ID	COMPONENT NO.	LOWER BOUND	VALUE	UPPER BOUND
42	1001	TEN110	110		7	-5.7600E+06	9.9023E+05	7.2000E+06
43	1001	TEN110	210		7	-5.7600E+06	8.0570E+05	7.2000E+06
44	1001	TEN110	120		7	-5.7600E+06	5.5349E+05	7.2000E+06
45	1001	TEN110	220		7	-5.7600E+06	4.0312E+05	7.2000E+06
46	1001	TEN110	310		7	-5.7600E+06	3.6640E+04	7.2000E+06
47	1002	COM110	110		8	-5.7600E+06	-9.9023E+05	7.2000E+06
48	1002	COM110	210		8	-5.7600E+06	-8.0570E+05	7.2000E+06
49	1002	COM110	120		8	-5.7600E+06	-5.5349E+05	7.2000E+06
50	1002	COM110	220		8	-5.7600E+06	-4.0312E+05	7.2000E+06
51	1002	COM110	310		8	-5.7600E+06	-3.9550E+04	7.2000E+06

I N I T I A L   A N A L Y S I S   S U B C A S E =   5

----- STRESS RESPONSES -----

INTERNAL ID	DRESP1 ID	RESPONSE LABEL	ELEMENT ID	VIEW ELM ID	COMPONENT NO.	LOWER BOUND	VALUE	UPPER BOUND
52	1001	TEN110	110		7	-5.7600E+06	1.2171E+05	7.2000E+06
53	1001	TEN110	210		7	-5.7600E+06	2.3355E+04	7.2000E+06
54	1001	TEN110	120		7	-5.7600E+06	7.4183E+04	7.2000E+06
55	1001	TEN110	220		7	-5.7600E+06	2.3071E+04	7.2000E+06
56	1001	TEN110	310		7	-5.7600E+06	5.8155E+05	7.2000E+06
57	1002	COM110	110		8	-5.7600E+06	-1.2370E+05	7.2000E+06
58	1002	COM110	210		8	-5.7600E+06	-2.1370E+04	7.2000E+06
59	1002	COM110	120		8	-5.7600E+06	-7.5083E+04	7.2000E+06
60	1002	COM110	220		8	-5.7600E+06	-2.2171E+04	7.2000E+06
61	1002	COM110	310		8	-5.7600E+06	-5.8145E+05	7.2000E+06

Listing 10-2 Output for Design Sensitivities of FSW Airplane (Continued)

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                         I N I T I A L   A N A L Y S I S   S U B C A S E =      6

                                    -----   FLUTTER RESPONSES   -----

 -----------------------------------------------------------------------------------------------------------
  INTERNAL   DRESP1   RESPONSE    MODE                    MACH                        LOWER                          UPPER
     ID        ID      LABEL       NO.      DENSITY        NO.        VELOCITY        BOUND         VALUE            BOUND
 -----------------------------------------------------------------------------------------------------------
       62         1   FLUTTER         4    2.3780E-03   9.0000E-01   1.0000E+03        N/A       -2.6559E-01        N/A
       63         1   FLUTTER         4    2.3780E-03   9.0000E-01   1.3000E+03        N/A       -2.6486E-01        N/A
       64         1   FLUTTER         4    2.3780E-03   9.0000E-01   1.5000E+03        N/A       -2.6429E-01        N/A
       65         1   FLUTTER         5    2.3780E-03   9.0000E-01   1.0000E+03        N/A       -6.5904E-01        N/A
       66         1   FLUTTER         5    2.3780E-03   9.0000E-01   1.3000E+03        N/A       -3.3484E-01        N/A
       67         1   FLUTTER         5    2.3780E-03   9.0000E-01   1.5000E+03        N/A       -2.3745E+00        N/A
       68         1   FLUTTER         6    2.3780E-03   9.0000E-01   1.0000E+03        N/A       -1.3052E-02        N/A
       69         1   FLUTTER         6    2.3780E-03   9.0000E-01   1.3000E+03        N/A       -1.7209E-02        N/A
       70         1   FLUTTER         6    2.3780E-03   9.0000E-01   1.5000E+03        N/A       -2.0199E-02        N/A
       71         1   FLUTTER         7    2.3780E-03   9.0000E-01   1.0000E+03        N/A       -2.0820E-01        N/A
       72         1   FLUTTER         7    2.3780E-03   9.0000E-01   1.3000E+03        N/A       -6.4710E-01        N/A
       73         1   FLUTTER         7    2.3780E-03   9.0000E-01   1.5000E+03        N/A        4.3816E-01        N/A
                         I N I T I A L   A N A L Y S I S   S U B C A S E =      7

                                    -----   FLUTTER RESPONSES   -----

 -----------------------------------------------------------------------------------------------------------
  INTERNAL   DRESP1   RESPONSE    MODE                    MACH                        LOWER                          UPPER
     ID        ID      LABEL       NO.      DENSITY        NO.        VELOCITY        BOUND         VALUE            BOUND
 -----------------------------------------------------------------------------------------------------------
       74        11   FLUTTER         4    2.3780E-03   1.2000E+00   1.0000E+03        N/A       -1.8059E-01        N/A
       75        11   FLUTTER         4    2.3780E-03   1.2000E+00   1.3000E+03        N/A       -1.8017E-01        N/A
       76        11   FLUTTER         4    2.3780E-03   1.2000E+00   1.5000E+03        N/A       -1.7979E-01        N/A
       77        11   FLUTTER         5    2.3780E-03   1.2000E+00   1.0000E+03        N/A       -1.9042E-01        N/A
       78        11   FLUTTER         5    2.3780E-03   1.2000E+00   1.3000E+03        N/A       -1.3412E-01        N/A
       79        11   FLUTTER         5    2.3780E-03   1.2000E+00   1.5000E+03        N/A        2.4370E-01        N/A
       80        11   FLUTTER         6    2.3780E-03   1.2000E+00   1.0000E+03        N/A       -1.4230E-02        N/A
       81        11   FLUTTER         6    2.3780E-03   1.2000E+00   1.3000E+03        N/A       -2.1561E-02        N/A
       82        11   FLUTTER         6    2.3780E-03   1.2000E+00   1.5000E+03        N/A       -2.6062E-02        N/A
       83        11   FLUTTER         7    2.3780E-03   1.2000E+00   1.0000E+03        N/A       -1.9368E-01        N/A
       84        11   FLUTTER         7    2.3780E-03   1.2000E+00   1.3000E+03        N/A       -2.8861E-01        N/A
       85        11   FLUTTER         7    2.3780E-03   1.2000E+00   1.5000E+03        N/A       -8.7125E-01        N/A
                                    ---- RETAINED DRESP2 RESPONSES ----

  ----------------------------------------------------------------------------------------------
      INTERNAL      DRESP2      RESPONSE     EQUATION         LOWER                             UPPER
         ID           ID         LABEL          ID            BOUND            VALUE            BOUND
  ----------------------------------------------------------------------------------------------
             1            5     RHSTWIST           5       -1.7450E-02       1.0550E-02       1.7450E-02
             2            6     LHSTWIST           5       -1.7450E-02       1.0550E-02       1.7450E-02
             3         2401     ROLLEFF          103        6.0000E-01 V     5.8929E-01       1.0000E+35
             4            5     RHSTWIST           5       -8.7260E-03       4.3018E-03       8.7260E-03
             5            6     LHSTWIST           5       -8.7260E-03       4.3018E-03       8.7260E-03
             6         2401     ROLLEFF          103        4.3000E-01 V     4.2517E-01       1.0000E+35
             7            4     GDAMP              4       -1.0000E+20      -2.9559E+00          N/A
             8            4     GDAMP              4       -1.0000E+20      -2.9486E+00          N/A
             9            4     GDAMP              4       -1.0000E+20      -2.9429E+00          N/A
            10            4     GDAMP              4       -1.0000E+20      -6.8904E+00          N/A
            11            4     GDAMP              4       -1.0000E+20      -3.6484E+00          N/A
            12            4     GDAMP              4       -1.0000E+20      -2.4045E+01          N/A
            13            4     GDAMP              4       -1.0000E+20      -4.3052E-01      -3.0000E-01
            14            4     GDAMP              4       -1.0000E+20      -4.7209E-01      -3.0000E-01
            15            4     GDAMP              4       -1.0000E+20      -5.0199E-01      -3.0000E-01
            16            4     GDAMP              4       -1.0000E+20      -2.3820E+00          N/A
            17            4     GDAMP              4       -1.0000E+20      -6.7710E+00          N/A
            18            4     GDAMP              4       -1.0000E+20       4.0816E+00      -3.0000E-01 V
            19           21     GDAMP              4       -1.0000E+20      -2.1059E+00          N/A
            20           21     GDAMP              4       -1.0000E+20      -2.1017E+00          N/A
            21           21     GDAMP              4       -1.0000E+20      -2.0979E+00          N/A
            22           21     GDAMP              4       -1.0000E+20      -2.2042E+00          N/A
            23           21     GDAMP              4       -1.0000E+20      -1.6412E+00          N/A
            24           21     GDAMP              4       -1.0000E+20       2.1370E+00      -3.0000E-01 V
            25           21     GDAMP              4       -1.0000E+20      -4.4230E-01      -3.0000E-01
            26           21     GDAMP              4       -1.0000E+20      -5.1561E-01      -3.0000E-01
            27           21     GDAMP              4       -1.0000E+20      -5.6062E-01      -3.0000E-01
            28           21     GDAMP              4       -1.0000E+20      -2.2368E+00          N/A
            29           21     GDAMP              4       -1.0000E+20      -3.1861E+00          N/A
            30           21     GDAMP              4       -1.0000E+20      -9.0125E+00          N/A
```

Listing 10-2 Output for Design Sensitivities of FSW Airplane (Continued)

```
                    *****************************************************************************
                    *                                                                           *
                    *    D E S I G N     S E N S I T I V I T Y     M A T R I X     O U T P U T   *
                    *                                                                           *
                    *                                                                           *
                    *    R E S P O N S E    S E N S I T I V I T Y    C O E F F I C I E N T S    *
                    *                                                                           *
                    *****************************************************************************

 ---------------------------------------------------------------------------------------------------------------------------------
    DRESP1 ID=        10             RESPONSE TYPE= WEIGHT                                                        SEID=          0
            RESP VALUE              DESIGN  VARIABLE  COEFFICIENT   DESIGN  VARIABLE  COEFFICIENT   DESIGN  VARIABLE  COEFFICIENT
 ---------------------------------------------------------------------------------------------------------------------------------
            1.6055E+04                  10 PBAR101    6.6667E+02        20  PBAR102    1.3333E+03       30  PBAR103    5.0000E+01

 ---------------------------------------------------------------------------------------------------------------------------------
    DRESP1 ID=       100             RESPONSE TYPE= DISP         GRID ID=       100     COMP NO=        5         SEID=          0
    SUBCASE  RESP VALUE             DESIGN  VARIABLE  COEFFICIENT   DESIGN  VARIABLE  COEFFICIENT   DESIGN  VARIABLE  COEFFICIENT
 ---------------------------------------------------------------------------------------------------------------------------------
          1  1.1291E-02                 10 PBAR101    2.3114E-04        20  PBAR102    5.5818E-06       30  PBAR103    5.3856E-05
          2  5.9761E-03                 10 PBAR101    1.1184E-04        20  PBAR102   -1.1226E-04       30  PBAR103    2.2700E-05

 ---------------------------------------------------------------------------------------------------------------------------------
    DRESP1 ID=       101             RESPONSE TYPE= DISP         GRID ID=       120     COMP NO=        5         SEID=          0
    SUBCASE  RESP VALUE             DESIGN  VARIABLE  COEFFICIENT   DESIGN  VARIABLE  COEFFICIENT   DESIGN  VARIABLE  COEFFICIENT
 ---------------------------------------------------------------------------------------------------------------------------------
-
          1  2.1841E-02                 10 PBAR101   -5.4312E-03        20  PBAR102   -4.8257E-03       30  PBAR103    8.5936E-05
          2  1.0278E-02                 10 PBAR101   -2.6175E-03        20  PBAR102   -1.6833E-03       30  PBAR103    3.6395E-05

 ---------------------------------------------------------------------------------------------------------------------------------
    DRESP1 ID=       201             RESPONSE TYPE= DISP         GRID ID=       220     COMP NO=        5         SEID=          0
    SUBCASE  RESP VALUE             DESIGN  VARIABLE  COEFFICIENT   DESIGN  VARIABLE  COEFFICIENT   DESIGN  VARIABLE  COEFFICIENT
 ---------------------------------------------------------------------------------------------------------------------------------
          1  2.1841E-02                 10 PBAR101   -5.4312E-03        20  PBAR102   -4.8257E-03       30  PBAR103    8.5936E-05
          2  1.0278E-02                 10 PBAR101   -2.6175E-03        20  PBAR102   -1.6833E-03       30  PBAR103    3.6395E-05

 ---------------------------------------------------------------------------------------------------------------------------------
    DRESP1 ID=      1001             RESPONSE TYPE= STRESS       ELEM ID=       110     COMP NO=        7         SEID=          0
    SUBCASE  RESP VALUE             DESIGN  VARIABLE  COEFFICIENT   DESIGN  VARIABLE  COEFFICIENT   DESIGN  VARIABLE  COEFFICIENT
 ---------------------------------------------------------------------------------------------------------------------------------
          1  1.1320E+06                 10 PBAR101   -1.2751E+06        20  PBAR102    1.3784E+05       30  PBAR103    5.3420E+03
          2  6.3774E+05                 10 PBAR101   -7.1814E+05        20  PBAR102    7.4133E+04       30  PBAR103    2.7142E+03
          3  1.1257E+06                 10 PBAR101   -1.2308E+06        20  PBAR102    9.5358E+04       30  PBAR103    4.8902E+03
          4  9.9023E+05                 10 PBAR101   -1.1054E+06        20  PBAR102    9.5749E+04       30  PBAR103    4.1038E+03
          5  1.2171E+05                 10 PBAR101   -1.4566E+05        20  PBAR102    1.6631E+04       30  PBAR103    8.1373E+03

 ---------------------------------------------------------------------------------------------------------------------------------
    DRESP1 ID=      1001             RESPONSE TYPE= STRESS       ELEM ID=       120     COMP NO=        7         SEID=          0
    SUBCASE  RESP VALUE             DESIGN  VARIABLE  COEFFICIENT   DESIGN  VARIABLE  COEFFICIENT   DESIGN  VARIABLE  COEFFICIENT
 ---------------------------------------------------------------------------------------------------------------------------------
          1  6.0417E+05                 10 PBAR101   -1.2258E+05        20  PBAR102   -4.9730E+05       30  PBAR103    2.1825E+03
          2  3.1092E+05                 10 PBAR101   -6.7731E+04        20  PBAR102   -2.4926E+05       30  PBAR103    1.1193E+03
          3  6.3006E+05                 10 PBAR101   -8.4899E+04        20  PBAR102   -5.5962E+05       30  PBAR103    2.4225E+03
          4  5.5349E+05                 10 PBAR101   -1.1303E+05        20  PBAR102   -4.7271E+05       30  PBAR103    1.4187E+03
          5  7.4183E+04                 10 PBAR101   -1.8728E+04        20  PBAR102   -5.9988E+04       30  PBAR103    3.8207E+03

 ---------------------------------------------------------------------------------------------------------------------------------
    DRESP1 ID=      1001             RESPONSE TYPE= STRESS       ELEM ID=       210     COMP NO=        7         SEID=          0
    SUBCASE  RESP VALUE             DESIGN  VARIABLE  COEFFICIENT   DESIGN  VARIABLE  COEFFICIENT   DESIGN  VARIABLE  COEFFICIENT
 ---------------------------------------------------------------------------------------------------------------------------------
          1  1.1320E+06                 10 PBAR101   -1.2751E+06        20  PBAR102    1.3784E+05       30  PBAR103    5.3420E+03
          2  6.3774E+05                 10 PBAR101   -7.1814E+05        20  PBAR102    7.4133E+04       30  PBAR103    2.7142E+03
          3  6.7018E+05                 10 PBAR101   -7.9121E+05        20  PBAR102    1.2356E+05       30  PBAR103    3.6571E+03
          4  8.0570E+05                 10 PBAR101   -9.1660E+05        20  PBAR102    1.2317E+05       30  PBAR103    4.4435E+03
          5  2.3355E+04                 10 PBAR101   -3.0537E+04        20  PBAR102    6.3935E+02       30  PBAR103   -7.6160E+03

 ---------------------------------------------------------------------------------------------------------------------------------
    DRESP1 ID=      1001             RESPONSE TYPE= STRESS       ELEM ID=       220     COMP NO=        7         SEID=          0
    SUBCASE  RESP VALUE             DESIGN  VARIABLE  COEFFICIENT   DESIGN  VARIABLE  COEFFICIENT   DESIGN  VARIABLE  COEFFICIENT
 ---------------------------------------------------------------------------------------------------------------------------------
          1  6.0417E+05                 10 PBAR101   -1.2258E+05        20  PBAR102   -4.9730E+05       30  PBAR103    2.1825E+03
          2  3.1092E+05                 10 PBAR101   -6.7731E+04        20  PBAR102   -2.4926E+05       30  PBAR103    1.1193E+03
          3  3.2654E+05                 10 PBAR101   -1.0909E+05        20  PBAR102   -2.2729E+05       30  PBAR103    1.0694E+03
          4  4.0312E+05                 10 PBAR101   -8.0957E+04        20  PBAR102   -3.1420E+05       30  PBAR103    2.0732E+03
          5  2.3071E+04                 10 PBAR101   -4.5597E+03        20  PBAR102   -2.2197E+04       30  PBAR103   -3.0255E+03
```

Listing 10-2 Output for Design Sensitivities of FSW Airplane (Continued)

```
---------------------------------------------------------------------------------------------------------
   DRESP1 ID=      1001              RESPONSE TYPE= STRESS      ELEM ID=      310     COMP NO=        7        SEID=        0
   SUBCASE  RESP VALUE              DESIGN  VARIABLE  COEFFICIENT  DESIGN  VARIABLE  COEFFICIENT  DESIGN  VARIABLE  COEFFICIENT
---------------------------------------------------------------------------------------------------------
         1   2.0050E+04                  10 PBAR101    3.1105E-07      20  PBAR102   -1.4334E-07      30  PBAR103   -1.8889E+05
         2   1.3367E+04                  10 PBAR101    5.9774E-06      20  PBAR102    6.9640E-06      30  PBAR103   -1.2593E+05
         3   9.4230E+04                  10 PBAR101    3.9829E+03      20  PBAR102    4.7956E+03      30  PBAR103   -9.3417E+05
         4   3.6640E+04                  10 PBAR101    7.7845E+02      20  PBAR102    5.7503E+02      30  PBAR103   -3.5738E+05
         5   5.8155E+05                  10 PBAR101    2.9939E+01      20  PBAR102    1.4809E+03      30  PBAR103   -5.7473E+06

---------------------------------------------------------------------------------------------------------
   DRESP1 ID=      1002              RESPONSE TYPE= STRESS      ELEM ID=      110     COMP NO=        8        SEID=        0
   SUBCASE  RESP VALUE              DESIGN  VARIABLE  COEFFICIENT  DESIGN  VARIABLE  COEFFICIENT  DESIGN  VARIABLE  COEFFICIENT
---------------------------------------------------------------------------------------------------------
         1  -1.1320E+06                  10 PBAR101    1.2751E+06      20  PBAR102   -1.3784E+05      30  PBAR103   -5.3420E+03
         2  -6.3774E+05                  10 PBAR101    7.1814E+05      20  PBAR102   -7.4133E+04      30  PBAR103   -2.7142E+03
         3  -1.1257E+06                  10 PBAR101    1.2308E+06      20  PBAR102   -9.5358E+04      30  PBAR103   -4.8902E+03
         4  -9.9023E+05                  10 PBAR101    1.1054E+06      20  PBAR102   -9.5749E+04      30  PBAR103   -4.1038E+03
         5  -1.2370E+05                  10 PBAR101    1.4762E+05      20  PBAR102   -1.7081E+04      30  PBAR103   -8.4105E+03

---------------------------------------------------------------------------------------------------------
   DRESP1 ID=      1002              RESPONSE TYPE= STRESS      ELEM ID=      120     COMP NO=        8        SEID=        0
   SUBCASE  RESP VALUE              DESIGN  VARIABLE  COEFFICIENT  DESIGN  VARIABLE  COEFFICIENT  DESIGN  VARIABLE  COEFFICIENT
---------------------------------------------------------------------------------------------------------
         1  -6.0417E+05                  10 PBAR101    1.2258E+05      20  PBAR102    4.9730E+05      30  PBAR103   -2.1825E+03
         2  -3.1092E+05                  10 PBAR101    6.7731E+04      20  PBAR102    2.4926E+05      30  PBAR103   -1.1193E+03
         3  -6.3006E+05                  10 PBAR101    8.4899E+04      20  PBAR102    5.5962E+05      30  PBAR103   -2.4225E+03
         4  -5.5349E+05                  10 PBAR101    1.1303E+05      20  PBAR102    4.7271E+05      30  PBAR103   -1.4187E+03
         5  -7.5083E+04                  10 PBAR101    1.8800E+04      20  PBAR102    6.0651E+04      30  PBAR103   -3.9447E+03

---------------------------------------------------------------------------------------------------------
   DRESP1 ID=      1002              RESPONSE TYPE= STRESS      ELEM ID=      210     COMP NO=        8        SEID=        0
   SUBCASE  RESP VALUE              DESIGN  VARIABLE  COEFFICIENT  DESIGN  VARIABLE  COEFFICIENT  DESIGN  VARIABLE  COEFFICIENT
---------------------------------------------------------------------------------------------------------
         1  -1.1320E+06                  10 PBAR101    1.2751E+06      20  PBAR102   -1.3784E+05      30  PBAR103   -5.3420E+03
         2  -6.3774E+05                  10 PBAR101    7.1814E+05      20  PBAR102   -7.4133E+04      30  PBAR103   -2.7142E+03
         3  -6.7018E+05                  10 PBAR101    7.9121E+05      20  PBAR102   -1.2356E+05      30  PBAR103   -3.6571E+03
         4  -8.0570E+05                  10 PBAR101    9.1660E+05      20  PBAR102   -1.2317E+05      30  PBAR103   -4.4435E+03
         5  -2.1370E+04                  10 PBAR101    2.8577E+04      20  PBAR102   -1.8895E+02      30  PBAR103    7.8892E+03

---------------------------------------------------------------------------------------------------------
   DRESP1 ID=      1002              RESPONSE TYPE= STRESS      ELEM ID=      220     COMP NO=        8        SEID=        0
   SUBCASE  RESP VALUE              DESIGN  VARIABLE  COEFFICIENT  DESIGN  VARIABLE  COEFFICIENT  DESIGN  VARIABLE  COEFFICIENT
---------------------------------------------------------------------------------------------------------
         1  -6.0417E+05                  10 PBAR101    1.2258E+05      20  PBAR102    4.9730E+05      30  PBAR103   -2.1825E+03
         2  -3.1092E+05                  10 PBAR101    6.7731E+04      20  PBAR102    2.4926E+05      30  PBAR103   -1.1193E+03
         3  -3.2654E+05                  10 PBAR101    1.0909E+05      20  PBAR102    2.2729E+05      30  PBAR103   -1.0694E+03
         4  -4.0312E+05                  10 PBAR101    8.0957E+04      20  PBAR102    3.1420E+05      30  PBAR103   -2.0732E+03
         5  -2.2171E+04                  10 PBAR101    4.4875E+03      20  PBAR102    2.1535E+04      30  PBAR103    3.1495E+03

---------------------------------------------------------------------------------------------------------
   DRESP1 ID=      1002              RESPONSE TYPE= STRESS      ELEM ID=      310     COMP NO=        8        SEID=        0
   SUBCASE  RESP VALUE              DESIGN  VARIABLE  COEFFICIENT  DESIGN  VARIABLE  COEFFICIENT  DESIGN  VARIABLE  COEFFICIENT
---------------------------------------------------------------------------------------------------------
         1  -2.3687E+04                  10 PBAR101    3.0959E-07      20  PBAR102   -4.7803E-07      30  PBAR103    2.2354E+05
         2  -1.5792E+04                  10 PBAR101   -6.2877E-06      20  PBAR102   -6.9640E-06      30  PBAR103    1.4902E+05
         3  -9.7140E+04                  10 PBAR101   -3.9829E+03      20  PBAR102   -4.7956E+03      30  PBAR103    9.6188E+05
         4  -3.9550E+04                  10 PBAR101   -7.7845E+02      20  PBAR102   -5.7503E+02      30  PBAR103    3.8509E+05
         5  -5.8145E+05                  10 PBAR101   -2.7395E+01      20  PBAR102   -1.4690E+03      30  PBAR103    5.7463E+06

---------------------------------------------------------------------------------------------------------
   DRESP1 ID=      1401              RESPONSE TYPE= STABDER      XID=        517     COMP NO=       4        SEID=        0
   SUBCASE  RESP VALUE     RUFLAG   DESIGN  VARIABLE  COEFFICIENT  DESIGN  VARIABLE  COEFFICIENT  DESIGN  VARIABLE  COEFFICIENT
---------------------------------------------------------------------------------------------------------
         1  2.6340E-01     UNREST        10 PBAR101    5.3692E-03      20  PBAR102    6.9823E-03      30  PBAR103    8.4060E-03
         2  2.1655E-01     UNREST        10 PBAR101    1.0492E-02      20  PBAR102    9.4378E-03      30  PBAR103   -3.3257E-03

---------------------------------------------------------------------------------------------------------
   DRESP1 ID=      1402              RESPONSE TYPE= STABDER      XID=        513     COMP NO=       4        SEID=        0
   SUBCASE  RESP VALUE     RUFLAG   DESIGN  VARIABLE  COEFFICIENT  DESIGN  VARIABLE  COEFFICIENT  DESIGN  VARIABLE  COEFFICIENT
---------------------------------------------------------------------------------------------------------
         1 -4.4697E-01     UNREST        10 PBAR101    1.7046E-02      20  PBAR102    1.3019E-02      30  PBAR103   -7.2612E-03
         2 -5.0933E-01     UNREST        10 PBAR101    8.9775E-03      20  PBAR102    4.9764E-03      30  PBAR103   -2.3476E-02
---------------------------------------------------------------------------------------------------------
   DRESP1 ID=         1              RESPONSE TYPE= FLUTTER     MODE NO=        4                          SEID=        0
                                    MACH NO.=        9.0000E-01  DENSITY=         2.3780E-03  VELOCITY=        1.5000E+03
   SUBCASE  RESP VALUE              DESIGN  VARIABLE  COEFFICIENT  DESIGN  VARIABLE  COEFFICIENT  DESIGN  VARIABLE  COEFFICIENT
---------------------------------------------------------------------------------------------------------
         6  -2.6429E-01                  10 PBAR101    1.1232E-02      20  PBAR102    1.9120E-02      30  PBAR103    9.6157E-04
```

Listing 10-2 Output for Design Sensitivities of FSW Airplane (Continued)

```
 ------------------------------------------------------------------------------------------------------------------------
    DRESP1 ID=        1              RESPONSE TYPE= FLUTTER      MODE NO=        5                               SEID=        0
                                     MACH NO.=        9.0000E-01  DENSITY=         2.3780E-03   VELOCITY=          1.0000E+03
    SUBCASE  RESP VALUE              DESIGN  VARIABLE COEFFICIENT  DESIGN  VARIABLE COEFFICIENT  DESIGN  VARIABLE COEFFICIENT
 ------------------------------------------------------------------------------------------------------------------------
          6  -6.5904E-01                10 PBAR101   -5.1125E-02       20  PBAR102   -3.9283E-02       30  PBAR103   -1.1174E-02

 ------------------------------------------------------------------------------------------------------------------------
    DRESP1 ID=        1              RESPONSE TYPE= FLUTTER      MODE NO=        5                               SEID=        0
                                     MACH NO.=        9.0000E-01  DENSITY=         2.3780E-03   VELOCITY=          1.3000E+03
    SUBCASE  RESP VALUE              DESIGN  VARIABLE COEFFICIENT  DESIGN  VARIABLE COEFFICIENT  DESIGN  VARIABLE COEFFICIENT
 ------------------------------------------------------------------------------------------------------------------------
          6  -3.3484E-01                10 PBAR101   -1.8379E+00       20  PBAR102   -8.8506E-01       30  PBAR103   -1.6660E-01

 ------------------------------------------------------------------------------------------------------------------------
    DRESP1 ID=        1              RESPONSE TYPE= FLUTTER      MODE NO=        5                               SEID=        0
                                     MACH NO.=        9.0000E-01  DENSITY=         2.3780E-03   VELOCITY=          1.5000E+03
    SUBCASE  RESP VALUE              DESIGN  VARIABLE COEFFICIENT  DESIGN  VARIABLE COEFFICIENT  DESIGN  VARIABLE COEFFICIENT
 ------------------------------------------------------------------------------------------------------------------------
          6  -2.3745E+00                10 PBAR101    2.1129E+00       20  PBAR102    1.3226E+00       30  PBAR103    2.3123E-01

 ------------------------------------------------------------------------------------------------------------------------
    DRESP1 ID=        1              RESPONSE TYPE= FLUTTER      MODE NO=        6                               SEID=        0
                                     MACH NO.=        9.0000E-01  DENSITY=         2.3780E-03   VELOCITY=          1.0000E+03
    SUBCASE  RESP VALUE              DESIGN  VARIABLE COEFFICIENT  DESIGN  VARIABLE COEFFICIENT  DESIGN  VARIABLE COEFFICIENT
 ------------------------------------------------------------------------------------------------------------------------
          6  -1.3052E-02                10 PBAR101    4.0045E-04       20  PBAR102    4.5097E-03       30  PBAR103    9.6771E-05

 ------------------------------------------------------------------------------------------------------------------------
    DRESP1 ID=        1              RESPONSE TYPE= FLUTTER      MODE NO=        6                               SEID=        0
                                     MACH NO.=        9.0000E-01  DENSITY=         2.3780E-03   VELOCITY=          1.3000E+03
    SUBCASE  RESP VALUE              DESIGN  VARIABLE COEFFICIENT  DESIGN  VARIABLE COEFFICIENT  DESIGN  VARIABLE COEFFICIENT
 ------------------------------------------------------------------------------------------------------------------------
          6  -1.7209E-02                10 PBAR101    5.8842E-04       20  PBAR102    5.9357E-03       30  PBAR103    1.3100E-04

 ------------------------------------------------------------------------------------------------------------------------
    DRESP1 ID=        1              RESPONSE TYPE= FLUTTER      MODE NO=        6                               SEID=        0
                                     MACH NO.=        9.0000E-01  DENSITY=         2.3780E-03   VELOCITY=          1.5000E+03
    SUBCASE  RESP VALUE              DESIGN  VARIABLE COEFFICIENT  DESIGN  VARIABLE COEFFICIENT  DESIGN  VARIABLE COEFFICIENT
 ------------------------------------------------------------------------------------------------------------------------
          6  -2.0199E-02                10 PBAR101    7.5416E-04       20  PBAR102    6.9691E-03       30  PBAR103    1.5589E-04

 ------------------------------------------------------------------------------------------------------------------------
    DRESP1 ID=        1              RESPONSE TYPE= FLUTTER      MODE NO=        7                               SEID=        0
                                     MACH NO.=        9.0000E-01  DENSITY=         2.3780E-03   VELOCITY=          1.0000E+03
    SUBCASE  RESP VALUE              DESIGN  VARIABLE COEFFICIENT  DESIGN  VARIABLE COEFFICIENT  DESIGN  VARIABLE COEFFICIENT
 ------------------------------------------------------------------------------------------------------------------------
          6  -2.0820E-01                10 PBAR101    9.2825E-02       20  PBAR102    7.2694E-02       30  PBAR103    5.5683E-03

 ------------------------------------------------------------------------------------------------------------------------
    DRESP1 ID=        1              RESPONSE TYPE= FLUTTER      MODE NO=        7                               SEID=        0
                                     MACH NO.=        9.0000E-01  DENSITY=         2.3780E-03   VELOCITY=          1.3000E+03
    SUBCASE  RESP VALUE              DESIGN  VARIABLE COEFFICIENT  DESIGN  VARIABLE COEFFICIENT  DESIGN  VARIABLE COEFFICIENT
 ------------------------------------------------------------------------------------------------------------------------
          6  -6.4710E-01                10 PBAR101    3.4163E+00       20  PBAR102    1.5893E+00       30  PBAR103    2.6908E-01

 ------------------------------------------------------------------------------------------------------------------------
    DRESP1 ID=        1              RESPONSE TYPE= FLUTTER      MODE NO=        7                               SEID=        0
                                     MACH NO.=        9.0000E-01  DENSITY=         2.3780E-03   VELOCITY=          1.5000E+03
    SUBCASE  RESP VALUE              DESIGN  VARIABLE COEFFICIENT  DESIGN  VARIABLE COEFFICIENT  DESIGN  VARIABLE COEFFICIENT
 ------------------------------------------------------------------------------------------------------------------------
          6   4.3816E-01                10 PBAR101   -5.9863E-01       20  PBAR102   -2.4313E-01       30  PBAR103   -5.0987E-02

 ------------------------------------------------------------------------------------------------------------------------
    DRESP1 ID=       11              RESPONSE TYPE= FLUTTER      MODE NO=        4                               SEID=        0
                                     MACH NO.=        1.2000E+00  DENSITY=         2.3780E-03   VELOCITY=          1.0000E+03
    SUBCASE  RESP VALUE              DESIGN  VARIABLE COEFFICIENT  DESIGN  VARIABLE COEFFICIENT  DESIGN  VARIABLE COEFFICIENT
 ------------------------------------------------------------------------------------------------------------------------
          7  -1.8059E-01                10 PBAR101    7.6673E-03       20  PBAR102    1.4068E-02       30  PBAR103    9.5315E-04

 ------------------------------------------------------------------------------------------------------------------------
    DRESP1 ID=       11              RESPONSE TYPE= FLUTTER      MODE NO=        4                               SEID=        0
                                     MACH NO.=        1.2000E+00  DENSITY=         2.3780E-03   VELOCITY=          1.3000E+03
    SUBCASE  RESP VALUE              DESIGN  VARIABLE COEFFICIENT  DESIGN  VARIABLE COEFFICIENT  DESIGN  VARIABLE COEFFICIENT
 ------------------------------------------------------------------------------------------------------------------------
          7  -1.8017E-01                10 PBAR101    8.1934E-03       20  PBAR102    1.4563E-02       30  PBAR103    8.7869E-04

 ------------------------------------------------------------------------------------------------------------------------
    DRESP1 ID=       11              RESPONSE TYPE= FLUTTER      MODE NO=        4                               SEID=        0
                                     MACH NO.=        1.2000E+00  DENSITY=         2.3780E-03   VELOCITY=          1.5000E+03
    SUBCASE  RESP VALUE              DESIGN  VARIABLE COEFFICIENT  DESIGN  VARIABLE COEFFICIENT  DESIGN  VARIABLE COEFFICIENT
 ------------------------------------------------------------------------------------------------------------------------
          7  -1.7979E-01                10 PBAR101    8.6307E-03       20  PBAR102    1.4993E-02       30  PBAR103    8.1764E-04
```

Listing 10-2 Output for Design Sensitivities of FSW Airplane (Continued)

```
 ----------------------------------------------------------------------------------------------------------------------------------
    DRESP1 ID=        11                RESPONSE TYPE= FLUTTER      MODE NO=         5                                 SEID=         0
                                       MACH NO.=          1.2000E+00   DENSITY=           2.3780E-03   VELOCITY=          1.0000E+03
    SUBCASE  RESP VALUE                DESIGN  VARIABLE  COEFFICIENT   DESIGN  VARIABLE  COEFFICIENT   DESIGN  VARIABLE  COEFFICIENT
 ----------------------------------------------------------------------------------------------------------------------------------
          7  -1.9042E-01                   10 PBAR101   -6.8025E-03       20  PBAR102    8.8211E-03       30  PBAR103   -1.8643E-04

 ----------------------------------------------------------------------------------------------------------------------------------
    DRESP1 ID=        11                RESPONSE TYPE= FLUTTER      MODE NO=         5                                 SEID=         0
                                       MACH NO.=          1.2000E+00   DENSITY=           2.3780E-03   VELOCITY=          1.3000E+03
    SUBCASE  RESP VALUE                DESIGN  VARIABLE  COEFFICIENT   DESIGN  VARIABLE  COEFFICIENT   DESIGN  VARIABLE  COEFFICIENT
 ----------------------------------------------------------------------------------------------------------------------------------
          7  -1.3412E-01                   10 PBAR101   -1.3725E-01       20  PBAR102   -7.0704E-02       30  PBAR103   -5.9324E-03

 ----------------------------------------------------------------------------------------------------------------------------------
    DRESP1 ID=        11                RESPONSE TYPE= FLUTTER      MODE NO=         5                                 SEID=         0
                                       MACH NO.=          1.2000E+00   DENSITY=           2.3780E-03   VELOCITY=          1.5000E+03
    SUBCASE  RESP VALUE                DESIGN  VARIABLE  COEFFICIENT   DESIGN  VARIABLE  COEFFICIENT   DESIGN  VARIABLE  COEFFICIENT
 ----------------------------------------------------------------------------------------------------------------------------------
          7   2.4370E-01                   10 PBAR101   -7.6813E-01       20  PBAR102   -3.1824E-01       30  PBAR103   -2.5450E-02

 ----------------------------------------------------------------------------------------------------------------------------------
    DRESP1 ID=        11                RESPONSE TYPE= FLUTTER      MODE NO=         6                                 SEID=         0
                                       MACH NO.=          1.2000E+00   DENSITY=           2.3780E-03   VELOCITY=          1.0000E+03
    SUBCASE  RESP VALUE                DESIGN  VARIABLE  COEFFICIENT   DESIGN  VARIABLE  COEFFICIENT   DESIGN  VARIABLE  COEFFICIENT
 ----------------------------------------------------------------------------------------------------------------------------------
          7  -1.4230E-02                   10 PBAR101    5.4536E-04       20  PBAR102    3.4202E-03       30  PBAR103    8.9851E-05

 ----------------------------------------------------------------------------------------------------------------------------------
    DRESP1 ID=        11                RESPONSE TYPE= FLUTTER      MODE NO=         6                                 SEID=         0
                                       MACH NO.=          1.2000E+00   DENSITY=           2.3780E-03   VELOCITY=          1.3000E+03
    SUBCASE  RESP VALUE                DESIGN  VARIABLE  COEFFICIENT   DESIGN  VARIABLE  COEFFICIENT   DESIGN  VARIABLE  COEFFICIENT
 ----------------------------------------------------------------------------------------------------------------------------------
          7  -2.1561E-02                   10 PBAR101    9.1562E-04       20  PBAR102    6.4704E-03       30  PBAR103    1.4957E-04

 ----------------------------------------------------------------------------------------------------------------------------------
    DRESP1 ID=        11                RESPONSE TYPE= FLUTTER      MODE NO=         6                                 SEID=         0
                                       MACH NO.=          1.2000E+00   DENSITY=           2.3780E-03   VELOCITY=          1.5000E+03
    SUBCASE  RESP VALUE                DESIGN  VARIABLE  COEFFICIENT   DESIGN  VARIABLE  COEFFICIENT   DESIGN  VARIABLE  COEFFICIENT
 ----------------------------------------------------------------------------------------------------------------------------------
          7  -2.6062E-02                   10 PBAR101    1.2152E-03       20  PBAR102    8.6061E-03       30  PBAR103    1.8970E-04

 ----------------------------------------------------------------------------------------------------------------------------------
    DRESP1 ID=        11                RESPONSE TYPE= FLUTTER      MODE NO=         7                                 SEID=         0
                                       MACH NO.=          1.2000E+00   DENSITY=           2.3780E-03   VELOCITY=          1.0000E+03
    SUBCASE  RESP VALUE                DESIGN  VARIABLE  COEFFICIENT   DESIGN  VARIABLE  COEFFICIENT   DESIGN  VARIABLE  COEFFICIENT
 ----------------------------------------------------------------------------------------------------------------------------------
          7  -1.9368E-01                   10 PBAR101    5.7920E-02       20  PBAR102    7.2949E-02       30  PBAR103    2.5005E-03

 ----------------------------------------------------------------------------------------------------------------------------------
    DRESP1 ID=        11                RESPONSE TYPE= FLUTTER      MODE NO=         7                                 SEID=         0
                                       MACH NO.=          1.2000E+00   DENSITY=           2.3780E-03   VELOCITY=          1.3000E+03
    SUBCASE  RESP VALUE                DESIGN  VARIABLE  COEFFICIENT   DESIGN  VARIABLE  COEFFICIENT   DESIGN  VARIABLE  COEFFICIENT
 ----------------------------------------------------------------------------------------------------------------------------------
          7  -2.8861E-01                   10 PBAR101    1.4714E-01       20  PBAR102    1.4863E-01       30  PBAR103    1.0006E-02

 ----------------------------------------------------------------------------------------------------------------------------------
    DRESP1 ID=        11                RESPONSE TYPE= FLUTTER      MODE NO=         7                                 SEID=         0
                                       MACH NO.=          1.2000E+00   DENSITY=           2.3780E-03   VELOCITY=          1.5000E+03
    SUBCASE  RESP VALUE                DESIGN  VARIABLE  COEFFICIENT   DESIGN  VARIABLE  COEFFICIENT   DESIGN  VARIABLE  COEFFICIENT
 ----------------------------------------------------------------------------------------------------------------------------------
          7  -8.7125E-01                   10 PBAR101    1.1033E+00       20  PBAR102    5.7474E-01       30  PBAR103    3.5244E-02


 ----------------------------------------------------------------------------------------------------------------------------------
    DRESP2 ID=         4                RESPONSE TYPE= SYNTHETIC                                                   SEID=         0
    SUBCASE  RESP VALUE  FREQ/TIME   DESIGN  VARIABLE  COEFFICIENT   DESIGN  VARIABLE  COEFFICIENT   DESIGN  VARIABLE  COEFFICIENT
 ----------------------------------------------------------------------------------------------------------------------------------
          6 -5.0199E-01  0.0000E+00       10 PBAR101    7.5416E-03       20  PBAR102    6.9691E-02       30  PBAR103    1.5589E-03
          6 -2.9429E+00  0.0000E+00       10 PBAR101    1.1232E-01       20  PBAR102    1.9120E-01       30  PBAR103    9.6157E-03
          6 -6.8904E+00  0.0000E+00       10 PBAR101   -5.1125E-01       20  PBAR102   -3.9283E-01       30  PBAR103   -1.1174E-01
          6 -3.6484E+00  0.0000E+00       10 PBAR101   -1.8379E+01       20  PBAR102   -8.8506E+00       30  PBAR103   -1.6660E+00
          6 -2.4045E+01  0.0000E+00       10 PBAR101    2.1129E+01       20  PBAR102    1.3226E+01       30  PBAR103    2.3123E+00
          6 -2.9486E+00  0.0000E+00       10 PBAR101    1.0853E-01       20  PBAR102    1.8817E-01       30  PBAR103    1.0261E-02
          6 -2.9559E+00  0.0000E+00       10 PBAR101    1.0446E-01       20  PBAR102    1.8530E-01       30  PBAR103    1.1054E-02
          6 -4.7209E-01  0.0000E+00       10 PBAR101    5.8842E-03       20  PBAR102    5.9357E-02       30  PBAR103    1.3100E-03
          6 -2.3820E+00  0.0000E+00       10 PBAR101    9.2825E-01       20  PBAR102    7.2694E-01       30  PBAR103    5.5683E-02
          6 -6.7710E+00  0.0000E+00       10 PBAR101    3.4163E+01       20  PBAR102    1.5893E+01       30  PBAR103    2.6908E+00
          6  4.0816E+00  0.0000E+00       10 PBAR101   -5.9863E+00       20  PBAR102   -2.4313E+00       30  PBAR103   -5.0987E-01
          6 -4.3052E-01  0.0000E+00       10 PBAR101    4.0045E-03       20  PBAR102    4.5097E-02       30  PBAR103    9.6771E-04
```

Listing 10-2 Output for Design Sensitivities of FSW Airplane (Continued)

```
-------------------------------------------------------------------------------------------------------------------------------
    DRESP2 ID=         5              RESPONSE TYPE= SYNTHETIC                                                    SEID=          0
    SUBCASE  RESP VALUE  FREQ/TIME   DESIGN  VARIABLE  COEFFICIENT    DESIGN  VARIABLE  COEFFICIENT    DESIGN  VARIABLE  COEFFICIENT
-------------------------------------------------------------------------------------------------------------------------------
          1  1.0550E-02  0.0000E+00        10 PBAR101   -5.6624E-03       20  PBAR102   -4.8313E-03       30  PBAR103    3.2080E-05
          2  4.3018E-03  0.0000E+00        10 PBAR101   -2.7294E-03       20  PBAR102   -1.5711E-03       30  PBAR103    1.3695E-05

-------------------------------------------------------------------------------------------------------------------------------
    DRESP2 ID=         6              RESPONSE TYPE= SYNTHETIC                                                    SEID=          0
    SUBCASE  RESP VALUE  FREQ/TIME   DESIGN  VARIABLE  COEFFICIENT    DESIGN  VARIABLE  COEFFICIENT    DESIGN  VARIABLE  COEFFICIENT
-------------------------------------------------------------------------------------------------------------------------------
          1  1.0550E-02  0.0000E+00        10 PBAR101   -5.6624E-03       20  PBAR102   -4.8313E-03       30  PBAR103    3.2080E-05
          2  4.3018E-03  0.0000E+00        10 PBAR101   -2.7294E-03       20  PBAR102   -1.5711E-03       30  PBAR103    1.3695E-05

-------------------------------------------------------------------------------------------------------------------------------
    DRESP2 ID=        21              RESPONSE TYPE= SYNTHETIC                                                    SEID=          0
    SUBCASE  RESP VALUE  FREQ/TIME   DESIGN  VARIABLE  COEFFICIENT    DESIGN  VARIABLE  COEFFICIENT    DESIGN  VARIABLE  COEFFICIENT
-------------------------------------------------------------------------------------------------------------------------------
          7 -2.2042E+00  0.0000E+00        10 PBAR101   -6.8025E-02       20  PBAR102    8.8211E-02       30  PBAR103   -1.8643E-03
          7 -3.1861E+00  0.0000E+00        10 PBAR101    1.4714E+00       20  PBAR102    1.4863E+00       30  PBAR103    1.0006E-01
          7 -2.2368E+00  0.0000E+00        10 PBAR101    5.7920E-01       20  PBAR102    7.2949E-01       30  PBAR103    2.5005E-02
          7 -5.6062E-01  0.0000E+00        10 PBAR101    1.2152E-02       20  PBAR102    8.6061E-02       30  PBAR103    1.8970E-03
          7 -5.1561E-01  0.0000E+00        10 PBAR101    9.1562E-03       20  PBAR102    6.4704E-02       30  PBAR103    1.4957E-03
          7 -4.4230E-01  0.0000E+00        10 PBAR101    5.4536E-03       20  PBAR102    3.4202E-02       30  PBAR103    8.9851E-04
          7  2.1370E+00  0.0000E+00        10 PBAR101   -7.6813E+00       20  PBAR102   -3.1824E+00       30  PBAR103   -2.5450E-01
          7 -1.6412E+00  0.0000E+00        10 PBAR101   -1.3725E+00       20  PBAR102   -7.0704E-01       30  PBAR103   -5.9324E-02
          7 -9.0125E+00  0.0000E+00        10 PBAR101    1.1033E+01       20  PBAR102    5.7474E+00       30  PBAR103    3.5244E-01
          7 -2.0979E+00  0.0000E+00        10 PBAR101    8.6307E-02       20  PBAR102    1.4993E-01       30  PBAR103    8.1764E-03
          7 -2.1017E+00  0.0000E+00        10 PBAR101    8.1934E-02       20  PBAR102    1.4563E-01       30  PBAR103    8.7869E-03
          7 -2.1059E+00  0.0000E+00        10 PBAR101    7.6673E-02       20  PBAR102    1.4068E-01       30  PBAR103    9.5315E-03

-------------------------------------------------------------------------------------------------------------------------------
    DRESP2 ID=      2401              RESPONSE TYPE= SYNTHETIC                                                    SEID=          0
    SUBCASE  RESP VALUE  FREQ/TIME   DESIGN  VARIABLE  COEFFICIENT    DESIGN  VARIABLE  COEFFICIENT    DESIGN  VARIABLE  COEFFICIENT
-------------------------------------------------------------------------------------------------------------------------------
          1  5.8929E-01  0.0000E+00        10 PBAR101    3.4486E-02       20  PBAR102    3.2786E-02       30  PBAR103    9.2332E-03
          2  4.2517E-01  0.0000E+00        10 PBAR101    2.8094E-02       20  PBAR102    2.2684E-02       30  PBAR103   -2.6126E-02

                                   ***************************************************************
                                   S U M M A R Y    O F    D E S I G N    C Y C L E    H I S T O R Y
                                   ***************************************************************

                                       NUMBER OF FINITE ELEMENT ANALYSES COMPLETED          1
                                       NUMBER OF OPTIMIZATIONS W.R.T. APPROXIMATE MODELS    0

                                              OBJECTIVE AND MAXIMUM CONSTRAINT HISTORY
          ---------------------------------------------------------------------------------------------------------------
                           OBJECTIVE FROM           OBJECTIVE FROM          FRACTIONAL ERROR          MAXIMUM VALUE
            CYCLE           APPROXIMATE                 EXACT                      OF                       OF
            NUMBER          OPTIMIZATION               ANALYSIS              APPROXIMATION              CONSTRAINT
          ---------------------------------------------------------------------------------------------------------------

            INITIAL                                  1.605500E+04                                       1.460522E+01
          ---------------------------------------------------------------------------------------------------------------

                                                       DESIGN VARIABLE HISTORY
-------------------------------------------------------------------------------------------------------------------------------
  INTERNAL |   EXTERNAL   |              |
   DV. ID. |    DV. ID.   |     LABEL    |   INITIAL    :       1       :       2       :       3       :       4       :       5       :
-------------------------------------------------------------------------------------------------------------------------------
         1 |          10  |  PBAR101     |   1.0000E+00 :
         2 |          20  |  PBAR102     |   1.0000E+00 :
         3 |          30  |  PBAR103     |   1.0000E-01 :
 *** USER INFORMATION MESSAGE 6464 (DOM12E)
     RUN TERMINATED DUE TO CASE CONTROL COMMAND DSAPRT(END=SENSITIVITY).
```

Aeroelastic Optimization of FSW Airplane (Example HA200B)

This example illustrates the aeroelastic optimization features of SOLution 200 when aeroelastic constraints are included along with stress and deflection constraints. The preceding Example HA200A illustrates the design sensitivity calculations. The Bulk Data input files are the same in the two examples except that the PARAM,CDIF = YES, and DSCREEN entries have been deleted, the DELB parameter has been set to its default value, and the title and subtitle have been changed to reflect the optimization task.

The DSAPRT case control command has been removed and move limits of 0.2 have been placed on the DESVARs. The value of P1 on the DOPTPRM entry has been set to 1 to obtain design output at every design cycle.

The design flight conditions and constraints have been discussed thoroughly in Example HA200A (p. 733). It is the sequence of iterations in the optimization process leading to the minimum weight optimized design that is of interest here. Figure 10-3 shows that the weight objective first increases to satisfy the design requirements and then converges rapidly to the final design. Figure 10-4, shows that the design requirements and objectives are met by increasing the thickness of the inboard bar significantly; the outboard bar decreases slightly, and the fin structure, which is relatively unimportant, increases. In figure 10-5, it is seen that the maximum constraint value starts with a value of over fourteen and rapidly reduces to zero.

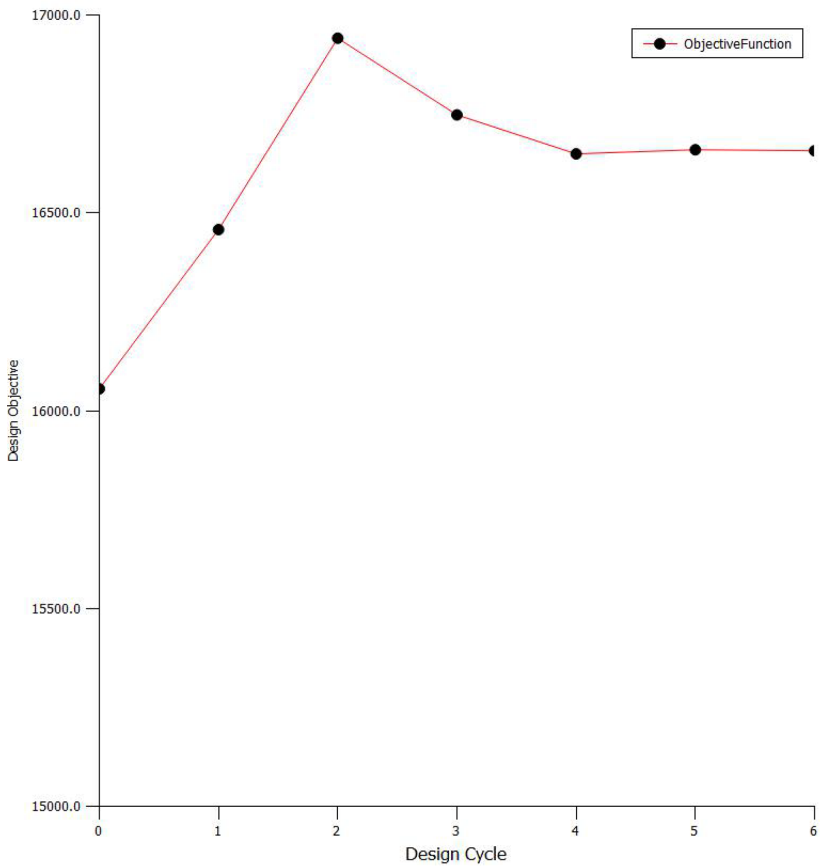


Figure 10-3 Convergence of Design Objective (Structural Weight)

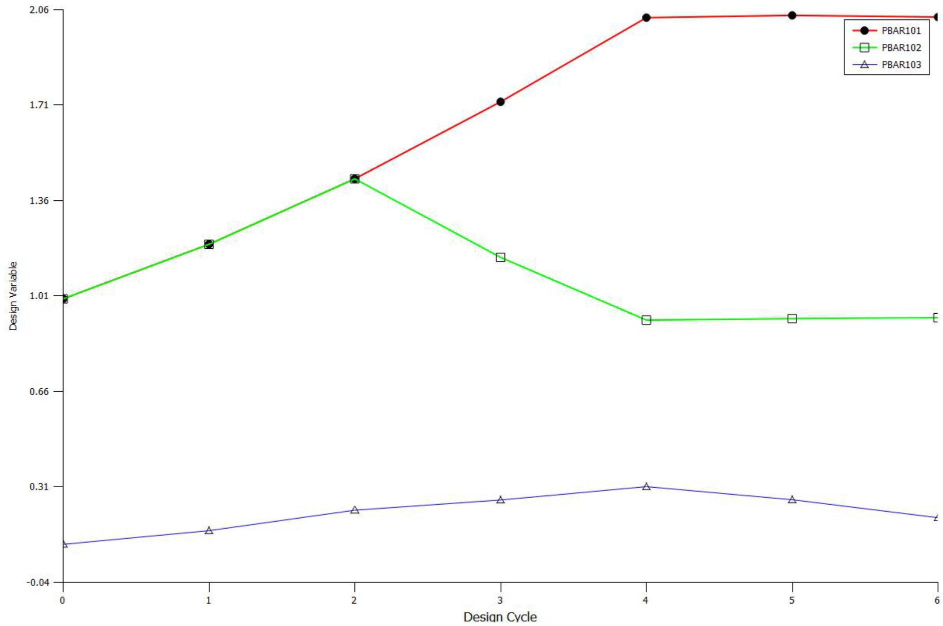


Figure 10-4 Convergence of Design Variables

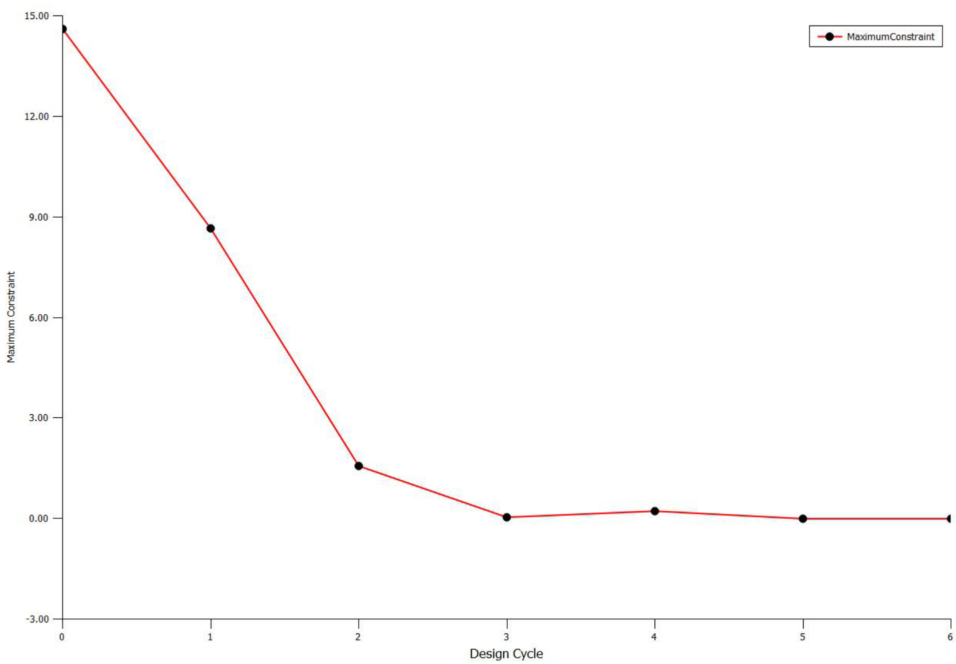


Figure 10-5 Maximum Constraint Design History

Listing 10-3 shows selected output from the optimization results file. A description of design optimization output can be found in Chapter 5 of the *MSC Nastran User's Guide for Design Sensitivity and Optimization*.

The abridged listing starts with a statement that the maximum constraint is 14.605. It can be determined that this constraint is associated with a flutter damping response that is equal to 0.4382, which is a very large value. The output that follows in Listing 10-3 is produced with P2 = 15 on the DOPTPRM entry and shows the results from the first optimization design cycle. In the series of tables included in this output, INPUT VALUE refers to exact values determined from the analysis. OUTPUT VALUES refers to approximate values as determined by the optimizer. In many cases, there is no approximation or the approximation is exact so that the output values are very accurate. Other values are determined from linear approximations, and an exact analysis could produce a significantly different value. The flutter damping response is a good example where a linear prediction can be expected to become less accurate as the design moves away from the starting point.

The results indicate that the weight increased from 16055.0 lbs to 16457.0 lbs for the first design cycle and that the design variables also increased significantly. The DESIGNED PROPERTIES output shows how the design variable changes affect the underlying structural properties. The DESIGN CONSTRAINTS ON RESPONSES is useful in that it gives some insight into which responses are driving the design. Because the DESIGN CONSTRAINT ON RESPONSES table lists responses by internal ID, it is necessary to refer to a second table to identify which responses are impacting the design. In this case, all the constrained responses are synthetic since EQUA is the RESPONSE TYPE for all of the constraints. This indicates that the constraints imposed by the stress limits have been screened out for this design cycle. The table on CONSTRAINTS ON DESIGNED PROPERTIES follows and indicates that in the process of reducing the constraint violation on the responses, certain property limits were exceeded. No problem occurred in this case, but too severe a property constraint violation could result in a meaningless structure (for example, one with negative bar areas). If this does occur, the user could restart the design from a better starting point or tighten the property move limits so that the properties are less likely to become meaningless.

The output next contains a series of tables that list the response values ordered by subcase. The response with an internal ID of 10 is the flutter damping value with the large violation of the design requirement. The DRESP2 responses indicate that the roll performance of the initial design is slightly deficient and predict that the designed structure will be adequate in this regard.

Convergence Check

Following the design information is a convergence check summary that always appears following an optimization cycle. The table is SOFT CONVERGENCE DECISION LOGIC, and soft convergence refers to a check of the results following an approximate optimization but before a re-analysis has been performed. In this case, it is seen that the convergence criteria all fail in that the objective, property values, and constraints all indicate that further progress is required.

Final Design Results

The output shown in Listing 10-3 now skips ahead to the results from the sixth and final design cycle. The DESIGNED CONSTRAINTS table shows that the maximum constraint value is -0.021, which indicates that the design is feasible (that is, the design satisfies the design constraint conditions). The RETAINED

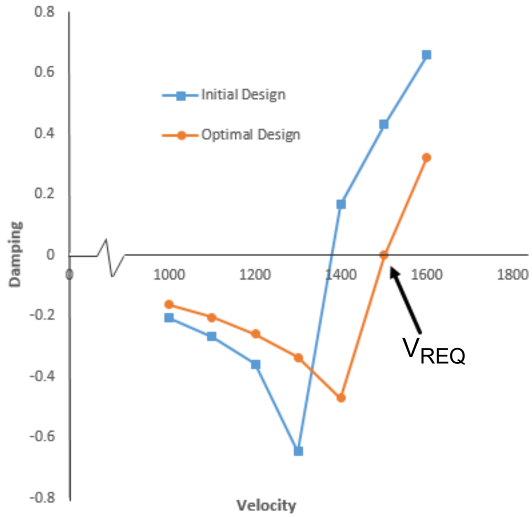
DRESP2 RESPONSES table indicates that the roll response requirements are being satisfied almost exactly and that one of the flutter constraints is also at the prescribed limit.

The soft convergence check indicates that the design variables and properties have changed enough to warrant further analysis. A final analysis then occurs and the subsonic flutter summary is shown in the listing. Attention is directed to POINT 7 in the summary where it is seen that the flutter curve crosses the zero damping boundary right at 1500.0 ft/sec. Figure 10-6 compares the V-g curves of the initial and final designs, indicating the subsonic flutter velocity has been increased from 1360.0 to 1500.0 ft/sec.

A hard convergence check is made and it indicates further design would not be profitable since the objective has changed by less than 0.1% and the design is feasible.

Design Histories

Listing 10-3 is concluded with two tables that present the design cycle histories depicted in Figure 10-3 and Figure 10-4. The first table shows the objective function and the maximum constraint value for each of the design cycles. It is seen that the objective increases from 16055.0 to 16656.7 pounds while the maximum constraint decreases from a value of 14.605 to an essentially zero value. Note that 14000 pounds of the weight is not-structural, non-designed mass. The second table presents a history of the design variables and shows that the weight increase can be attributed to a more than doubling of the structural properties of the inboard bar while making less significant changes in the remaining design variables.



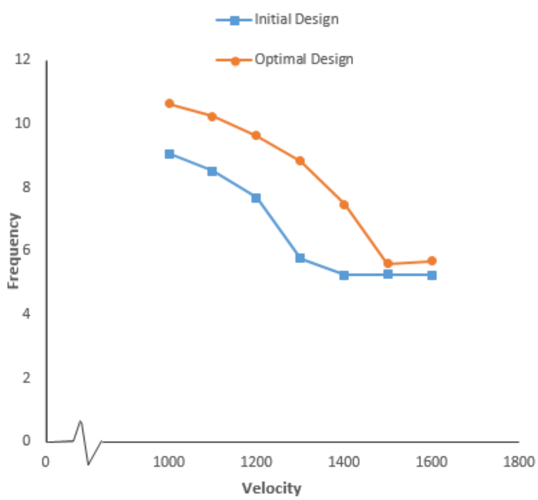


Figure 10-6 The Critical V-g-V-f Curves for the Forward Swept Wing Aeroelastic Optimization Example

Listing 10-3 Output from Optimization of FSW Airplane

```
THIS IS THE FIRST ANALYSIS - NO CONVERGENCE CHECK
-------------------------------------------------------
 MAXIMUM VALUE OF CONSTRAINTS            :  1.4605E+01
-------------------------------------------------------
           ********************************************************************
           *                                                                  *
           *                                                                  *
           *                D E S I G N    O P T I M I Z A T I O N            *
           *                                                                  *
           *                                                                  *
           ********************************************************************


                        *******************************************
                        *                                         *
                        *      D E S I G N   C Y C L E       1    *
                        *                                         *
                        *******************************************

            *****   OPTIMIZATION RESULTS BASED ON THE APPROXIMATE MODEL   *****
```

----- DESIGN OBJECTIVE -----

INTERNAL RESPONSE ID	DRESPx	RESPONSE TYPE	MINIMIZE OR MAXIMIZE	SUPERELEMENT ID	SUBCASE ID	INPUT VALUE	OUTPUT VALUE
1	DRESP1	WEIGHT	MINIMIZE	0	0	1.6055E+04	1.6457E+04

----- DESIGN VARIABLES -----

INTERNAL ID	DESVAR ID	LABEL	LOWER BOUND	INPUT VALUE	OUTPUT VALUE	UPPER BOUND
1	10	PBAR101	1.0000E-03	1.0000E+00	1.2000E+00	1.0000E+02
2	20	PBAR102	1.0000E-03	1.0000E+00	1.2000E+00	1.0000E+02
3	30	PBAR103	1.0000E-03	1.0000E-01	1.5000E-01	1.0000E+02

----- DESIGNED PROPERTIES -----

PROPERTY TYPE	PROPERTY ID	PROPERTY NAME	TYPE OF PROPERTY	LOWER BOUND	INPUT VALUE	OUTPUT VALUE	UPPER BOUND
PBAR	101	A	DVPREL1	N/A	1.5000E+00	1.8000E+00	N/A
PBAR	101	I1	DVPREL1	N/A	1.7361E-01	2.0833E-01	N/A
PBAR	101	I2	DVPREL1	N/A	2.0000E+00	2.4000E+00	N/A
PBAR	101	J	DVPREL1	N/A	4.6296E-01	5.5556E-01	N/A
PBAR	102	A	DVPREL1	N/A	1.5000E+00	1.8000E+00	N/A
PBAR	102	I1	DVPREL1	N/A	1.7361E-01	2.0833E-01	N/A
PBAR	102	I2	DVPREL1	N/A	2.0000E+00	2.4000E+00	N/A
PBAR	102	J	DVPREL1	N/A	4.6296E-01	5.5556E-01	N/A
PBAR	103	A	DVPREL1	N/A	1.5000E-01	2.2500E-01	N/A
PBAR	103	I1	DVPREL1	N/A	1.7361E-02	2.6042E-02	N/A
PBAR	103	I2	DVPREL1	N/A	2.0000E-01	3.0000E-01	N/A
PBAR	103	J	DVPREL1	N/A	4.6296E-02	6.9444E-02	N/A

----- DESIGN CONSTRAINTS ON RESPONSES -----

(MAXIMUM RESPONSE CONSTRAINTS MARKED WITH **)

INTERNAL ID	DCONSTR ID	INTERNAL RESPONSE ID	EXTERNAL DRESPx ID	RESPONSE TYPE	L/U FLAG	INTERNAL REGION ID	SUBCASE ID	INPUT VALUE	OUTPUT VALUE
1	50	1	5	EQUA	UPPER	5	1	-3.9543E-01	-4.9560E-01
2	50	2	6	EQUA	UPPER	6	1	-3.9543E-01	-4.9560E-01
3	50	3	2401	EQUA	LOWER	2401	1	1.7847E-02	-1.5593E-03
4	60	4	2401	EQUA	LOWER	2401	2	1.1240E-02	-6.4694E-03
5	6	5	4	EQUA	UPPER	4	6	-4.3507E-01	-4.0768E-01
6	6	6	4	EQUA	UPPER	4	6	1.4605E+01**	9.8721E+00**
7	7	7	21	EQUA	UPPER	21	7	8.1234E+00	2.0597E+00
8	7	8	21	EQUA	UPPER	21	7	-4.7432E-01	-4.5219E-01

Listing 10-3 Output from Optimization of FSW Airplane (Continued)

```
                         -------------------------------------------------------------------
                         |       R E S P O N S E S     IN    D E S I G N    M O D E L        |
                         -------------------------------------------------------------------

                                            (N/A - BOUND NOT ACTIVE OR AVAILABLE)
                                         (*** VIOLATED RESPONSES MARKED WITH V ***)
                                          (*** ACTIVE RESPONSES MARKED WITH A ***)

                                                -----    WEIGHT RESPONSE    -----

 -------------------------------------------------------------------------------------------------------------------------
     INTERNAL    DRESP1     RESPONSE     ROW        COLUMN         LOWER          INPUT          OUTPUT           UPPER
        ID         ID        LABEL        ID          ID           BOUND          VALUE           VALUE           BOUND
 -------------------------------------------------------------------------------------------------------------------------
         1        10       WEIGHT        3          3          N/A         1.6055E+04    1.6457E+04       N/A

                              D E S I G N    C Y C L E =       1    S U B C A S E =       1

                                            -----    DISPLACEMENT RESPONSES    -----

 -------------------------------------------------------------------------------------------------------------------------
     INTERNAL    DRESP1     RESPONSE     GRID     COMPONENT        LOWER          INPUT          OUTPUT           UPPER
        ID         ID        LABEL        ID         NO.           BOUND          VALUE           VALUE           BOUND
 -------------------------------------------------------------------------------------------------------------------------
           2        100    RTROT          100          5        N/A          1.1291E-02    1.1332E-02       N/A
           3        101    RTIPROT        120          5        N/A          2.1841E-02    2.0134E-02       N/A
           4        201    LTIPROT        220          5        N/A          2.1841E-02    2.0134E-02       N/A

                                        -----    STABILITY DERIVATIVE RESPONSES    -----

 -------------------------------------------------------------------------------------------------------------------------
                                 RESTRAINED /              AESTAT /
  INTERNAL   DRESP1    RESPONSE  UNRESTRAINED  COMPONENT  AESURF         LOWER          INPUT          OUTPUT          UPPER
     ID        ID       LABEL        FLAG          NO.       ID          BOUND          VALUE           VALUE          BOUND
 -------------------------------------------------------------------------------------------------------------------------
         5      1401   CLDELTA       0             4        517        N/A          2.6340E-01    2.6574E-01        N/A
         6      1402   CLP           0             4        513        N/A         -4.4697E-01   -4.4220E-01        N/A

                              D E S I G N    C Y C L E =       1    S U B C A S E =       2

                                        -----    STABILITY DERIVATIVE RESPONSES    -----

 -------------------------------------------------------------------------------------------------------------------------
                                 RESTRAINED /              AESTAT /
  INTERNAL   DRESP1    RESPONSE  UNRESTRAINED  COMPONENT  AESURF         LOWER          INPUT          OUTPUT          UPPER
     ID        ID       LABEL        FLAG          NO.       ID          BOUND          VALUE           VALUE          BOUND
 -------------------------------------------------------------------------------------------------------------------------
         7      1401   CLDELTA       0             4        517        N/A          2.1655E-01    2.1976E-01        N/A
         8      1402   CLP           0             4        513        N/A         -5.0933E-01   -5.0779E-01        N/A

                              D E S I G N    C Y C L E =       1    S U B C A S E =       6

                                             -----    FLUTTER RESPONSES    -----

 ---------------------------------------------------------------------------------------------------------------------------
INTERNAL  DRESP1 RESPONSE    MODE                    MACH                       LOWER         INPUT        OUTPUT         UPPER
   ID       ID    LABEL      NO.       DENSITY        NO.        VELOCITY       BOUND         VALUE         VALUE         BOUND
 ---------------------------------------------------------------------------------------------------------------------------
    9        1 FLUTTER         6   2.3780E-03   9.0000E-01   1.0000E+03      N/A        -1.3052E-02  -1.2231E-02      N/A
   10        1 FLUTTER          7   2.3780E-03   9.0000E-01   1.5000E+03      N/A         4.3816E-01   2.9616E-01      N/A
```

Listing 10-3 Output from Optimization of FSW Airplane (Continued)

```
                         D E S I G N   C Y C L E =      1    S U B C A S E =      7

                                   -----   FLUTTER RESPONSES    -----

 --------------------------------------------------------------------------------------------------------------------------------
 INTERNAL  DRESP1 RESPONSE     MODE                  MACH                       LOWER         INPUT        OUTPUT         UPPER
    ID       ID    LABEL       NO.      DENSITY       NO.        VELOCITY       BOUND         VALUE         VALUE         BOUND
 --------------------------------------------------------------------------------------------------------------------------------
    11       11 FLUTTER          5   2.3780E-03   1.2000E+00   1.5000E+03      N/A        2.4370E-01   6.1791E-02      N/A
    12       11 FLUTTER          6   2.3780E-03   1.2000E+00   1.0000E+03      N/A       -1.4230E-02  -1.3566E-02      N/A

                                   ---- RETAINED DRESP2 RESPONSES ----

   ------------------------------------------------------------------------------------------------------------------------------
        INTERNAL       DRESP2       RESPONSE      EQUATION         LOWER            INPUT           OUTPUT            UPPER
           ID            ID          LABEL           ID            BOUND            VALUE            VALUE            BOUND
   ------------------------------------------------------------------------------------------------------------------------------
            1             5        RHSTWIST           5             N/A          1.0550E-02       8.8018E-03       1.7450E-02
            2             6        LHSTWIST           5             N/A          1.0550E-02       8.8018E-03       1.7450E-02
            3          2401        ROLLEFF          103        6.0000E-01 A      5.8929E-01       6.0094E-01          N/A
            4          2401        ROLLEFF          103        4.3000E-01 A      4.2517E-01       4.3278E-01          N/A
            5             4        GDAMP              4             N/A         -4.3052E-01      -4.2231E-01      -3.0000E-01
            6             4        GDAMP              4             N/A          4.0816E+00       2.6616E+00      -3.0000E-01 V
            7            21        GDAMP              4             N/A          2.1370E+00       3.1791E-01      -3.0000E-01 V
            8            21        GDAMP              4             N/A         -4.4230E-01      -4.3566E-01      -3.0000E-01


                    ***************************************************************************************
                    INSPECTION OF CONVERGENCE DATA FOR THE OPTIMAL DESIGN WITH RESPECT TO APPROXIMATE MODELS
                                               (SOFT CONVERGENCE DECISION LOGIC)
                    ***************************************************************************************

                       MAXIMUM OF RELATIVE PROP. CHANGES     5.0000E-01 MUST BE LESS THAN   1.0000E-03
                                                     --- AND ---
                       MAXIMUM OF RELATIVE D.V. CHANGES      5.0000E-01  MUST BE LESS THAN   1.0000E-03
                    ***************************************************************************************

NOTE: Hundreds of pages of output have been deleted
                             *******************************************************************
                             *                                                                 *
                             *                                                                 *
                             *                D E S I G N    O P T I M I Z A T I O N           *
                             *                                                                 *
                             *                                                                 *
                             *******************************************************************


                                          *******************************************
                                          *                                         *
                                          *     D E S I G N   C Y C L E      6      *
                                          *                                         *
                                          *******************************************


                              *****   OPTIMIZATION RESULTS BASED ON THE APPROXIMATE MODEL   *****

                                          -----   DESIGN OBJECTIVE   -----

   ------------------------------------------------------------------------------------------------------------------------------
               INTERNAL                            MINIMIZE
               RESPONSE                RESPONSE       OR       SUPERELEMENT    SUBCASE          INPUT           OUTPUT
                  ID        DRESPx       TYPE      MAXIMIZE         ID            ID            VALUE            VALUE
   ------------------------------------------------------------------------------------------------------------------------------
                   1        DRESP1      WEIGHT     MINIMIZE             0            0       1.6659E+04       1.6657E+04

                                          -----   DESIGN VARIABLES   -----

   ------------------------------------------------------------------------------------------------------------------------------
             INTERNAL       DESVAR                         LOWER              INPUT             OUTPUT             UPPER
                ID            ID           LABEL           BOUND              VALUE              VALUE             BOUND
   ------------------------------------------------------------------------------------------------------------------------------
                 1            10          PBAR101       1.0000E-03         2.0394E+00         2.0332E+00         1.0000E+02
                 2            20          PBAR102       1.0000E-03         9.2741E-01         9.3102E-01         1.0000E+02
                 3            30          PBAR103       1.0000E-03         2.6339E-01         1.9755E-01         1.0000E+02
```

Listing 10-3 Output from Optimization of FSW Airplane (Continued)

----- DESIGNED PROPERTIES -----

PROPERTY TYPE	PROPERTY ID	PROPERTY NAME	TYPE OF PROPERTY	LOWER BOUND	INPUT VALUE	OUTPUT VALUE	UPPER BOUND
PBAR	101	A	DVPREL1	N/A	3.0591E+00	3.0498E+00	N/A
PBAR	101	I1	DVPREL1	N/A	3.5406E-01	3.5299E-01	N/A
PBAR	101	I2	DVPREL1	N/A	4.0788E+00	4.0665E+00	N/A
PBAR	101	J	DVPREL1	N/A	9.4416E-01	9.4131E-01	N/A
PBAR	102	A	DVPREL1	N/A	1.3911E+00	1.3965E+00	N/A
PBAR	102	I1	DVPREL1	N/A	1.6101E-01	1.6163E-01	N/A
PBAR	102	I2	DVPREL1	N/A	1.8548E+00	1.8620E+00	N/A
PBAR	102	J	DVPREL1	N/A	4.2936E-01	4.3103E-01	N/A
PBAR	103	A	DVPREL1	N/A	3.9509E-01	2.9632E-01	N/A
PBAR	103	I1	DVPREL1	N/A	4.5728E-02	3.4297E-02	N/A
PBAR	103	I2	DVPREL1	N/A	5.2679E-01	3.9510E-01	N/A
PBAR	103	J	DVPREL1	N/A	1.2194E-01	9.1458E-02	N/A

----- DESIGN CONSTRAINTS ON RESPONSES -----

(MAXIMUM RESPONSE CONSTRAINTS MARKED WITH **)

INTERNAL ID	DCONSTR ID	INTERNAL RESPONSE ID	EXTERNAL DRESPx ID	RESPONSE TYPE	L/U FLAG	INTERNAL REGION ID	SUBCASE ID	INPUT VALUE	OUTPUT VALUE
1	50	1	2401	EQUA	LOWER	2401	1	-8.0413E-03**	-7.9924E-03
2	60	2	2401	EQUA	LOWER	2401	2	-1.4151E-02	-1.5012E-02
3	6	3	4	EQUA	UPPER	4	6	-4.4220E-01	-4.4202E-01
4	6	4	4	EQUA	UPPER	4	6	-2.1428E-02	-3.8449E-07**
5	7	5	21	EQUA	UPPER	21	7	-4.7715E-01	-4.7708E-01

| R E S P O N S E S IN D E S I G N M O D E L |

(N/A - BOUND NOT ACTIVE OR AVAILABLE)
(*** VIOLATED RESPONSES MARKED WITH V ***)
(*** ACTIVE RESPONSES MARKED WITH A ***)

----- WEIGHT RESPONSE -----

INTERNAL ID	DRESP1 ID	RESPONSE LABEL	ROW ID	COLUMN ID	LOWER BOUND	INPUT VALUE	OUTPUT VALUE	UPPER BOUND
1	10	WEIGHT	3	3	N/A	1.6659E+04	1.6657E+04	N/A

D E S I G N C Y C L E = 6 S U B C A S E = 1

----- STABILITY DERIVATIVE RESPONSES -----

INTERNAL ID	DRESP1 ID	RESPONSE LABEL	RESTRAINED / UNRESTRAINED FLAG	COMPONENT NO.	AESTAT / AESURF ID	LOWER BOUND	INPUT VALUE	OUTPUT VALUE	UPPER BOUND
2	1401	CLDELTA	0	4	517	N/A	2.6620E-01	2.6611E-01	N/A
3	1402	CLP	0	4	513	N/A	-4.4012E-01	-4.4000E-01	N/A

D E S I G N C Y C L E = 6 S U B C A S E = 2

----- STABILITY DERIVATIVE RESPONSES -----

INTERNAL ID	DRESP1 ID	RESPONSE LABEL	RESTRAINED / UNRESTRAINED FLAG	COMPONENT NO.	AESTAT / AESURF ID	LOWER BOUND	INPUT VALUE	OUTPUT VALUE	UPPER BOUND
4	1401	CLDELTA	0	4	517	N/A	2.2103E-01	2.2109E-01	N/A
5	1402	CLP	0	4	513	N/A	-5.0685E-01	-5.0655E-01	N/A

Listing 10-3 Output from Optimization of FSW Airplane (Continued)

```
                                   D E S I G N   C Y C L E =       6    S U B C A S E =       6

                                                ----    FLUTTER RESPONSES    ----

 -----------------------------------------------------------------------------------------------------------------------
 INTERNAL  DRESP1 RESPONSE    MODE                   MACH                      LOWER         INPUT        OUTPUT        UPPER
    ID       ID    LABEL      NO.       DENSITY       NO.       VELOCITY       BOUND         VALUE         VALUE        BOUND
 -----------------------------------------------------------------------------------------------------------------------
      6        1 FLUTTER        6   2.3780E-03   9.0000E-01   1.0000E+03      N/A        -1.3266E-02  -1.3261E-02     N/A
      7        1 FLUTTER        7   2.3780E-03   9.0000E-01   1.5000E+03      N/A        -6.4284E-04  -1.1535E-08     N/A
                                   D E S I G N   C Y C L E =       6    S U B C A S E =       7

                                                ----    FLUTTER RESPONSES    ----

 -----------------------------------------------------------------------------------------------------------------------
 INTERNAL  DRESP1 RESPONSE    MODE                   MACH                      LOWER         INPUT        OUTPUT        UPPER
    ID       ID    LABEL      NO.       DENSITY       NO.       VELOCITY       BOUND         VALUE         VALUE        BOUND
 -----------------------------------------------------------------------------------------------------------------------
      8       11 FLUTTER        6   2.3780E-03   1.2000E+00   1.0000E+03      N/A        -1.4315E-02  -1.4312E-02     N/A

                                                ---- RETAINED DRESP2 RESPONSES ----

   ---------------------------------------------------------------------------------------------------------------------
      INTERNAL        DRESP2        RESPONSE      EQUATION          LOWER            INPUT            OUTPUT            UPPER
         ID             ID           LABEL          ID              BOUND            VALUE             VALUE            BOUND
   ---------------------------------------------------------------------------------------------------------------------
             1          2401        ROLLEFF          103        6.0000E-01 A       6.0482E-01       6.0480E-01          N/A
             2          2401        ROLLEFF          103        4.3000E-01 A       4.3608E-01       4.3645E-01          N/A
             3             4        GDAMP              4            N/A           -4.3266E-01      -4.3261E-01      -3.0000E-01
             4             4        GDAMP              4            N/A           -3.0643E-01      -3.0000E-01      -3.0000E-01 A
             5            21        GDAMP              4            N/A           -4.4315E-01      -4.4312E-01      -3.0000E-01


                        ****************************************************************************************
                        INSPECTION OF CONVERGENCE DATA FOR THE OPTIMAL DESIGN WITH RESPECT TO APPROXIMATE MODELS
                                                   (SOFT CONVERGENCE DECISION LOGIC)
                        ****************************************************************************************

                           MAXIMUM OF RELATIVE PROP. CHANGES      2.4998E-01 MUST BE LESS THAN   1.0000E-03
                                                            --- AND ---
                           MAXIMUM OF RELATIVE D.V. CHANGES       2.4998E-01  MUST BE LESS THAN   1.0000E-03
                        ****************************************************************************************
0                                                        FLUTTER  SUMMARY
                         CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = ASYMMETRIC
     POINT =     1      MACH NUMBER =  0.9000     DENSITY RATIO =  1.0000E+00     METHOD = PK


     KFREQ          1./KFREQ        VELOCITY          DAMPING         FREQUENCY           COMPLEX   EIGENVALUE
      0.0000      1.0000000E+25    1.0000000E+03    -4.9980866E-09    0.0000000E+00    -3.4643737E-07     0.0000000E+00
      0.0000      1.0000000E+25    1.1000000E+03    -5.7627088E-09    0.0000000E+00    -4.3938004E-07     0.0000000E+00
      0.0000      1.0000000E+25    1.2000000E+03    -6.6010367E-09    0.0000000E+00    -5.4905311E-07     0.0000000E+00
      0.0000      1.0000000E+25    1.3000000E+03    -7.5134058E-09    0.0000000E+00    -6.7701947E-07     0.0000000E+00
      0.0000      1.0000000E+25    1.4000000E+03    -8.5000839E-09    0.0000000E+00    -8.2484474E-07     0.0000000E+00
      0.0000      1.0000000E+25    1.5000000E+03    -9.5613662E-09    0.0000000E+00    -9.9410480E-07     0.0000000E+00
      0.0000      1.0000000E+25    1.6000000E+03    -1.0697589E-08    0.0000000E+00    -1.1863883E-06     0.0000000E+00
0                                                        FLUTTER  SUMMARY
                         CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = ASYMMETRIC
     POINT =     2      MACH NUMBER =  0.9000     DENSITY RATIO =  1.0000E+00     METHOD = PK


     KFREQ          1./KFREQ        VELOCITY          DAMPING         FREQUENCY           COMPLEX   EIGENVALUE
      0.0000      1.0000000E+25    1.0000000E+03     8.4410030E-06    0.0000000E+00     5.8507968E-04     0.0000000E+00
      0.0000      1.0000000E+25    1.1000000E+03     8.4463141E-06    0.0000000E+00     6.4399260E-04     0.0000000E+00
      0.0000      1.0000000E+25    1.2000000E+03     8.4521521E-06    0.0000000E+00     7.0302297E-04     0.0000000E+00
      0.0000      1.0000000E+25    1.3000000E+03     8.4585231E-06    0.0000000E+00     7.6218229E-04     0.0000000E+00
      0.0000      1.0000000E+25    1.4000000E+03     8.4654236E-06    0.0000000E+00     8.2148132E-04     0.0000000E+00
      0.0000      1.0000000E+25    1.5000000E+03     8.4728899E-06    0.0000000E+00     8.8093484E-04     0.0000000E+00
      0.0000      1.0000000E+25    1.6000000E+03     8.4808892E-06    0.0000000E+00     9.4055097E-04     0.0000000E+00
0                                                        FLUTTER  SUMMARY
                         CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = ASYMMETRIC
     POINT =     3      MACH NUMBER =  0.9000     DENSITY RATIO =  1.0000E+00     METHOD = PK


     KFREQ          1./KFREQ        VELOCITY          DAMPING         FREQUENCY           COMPLEX   EIGENVALUE
      0.0000      1.0000000E+25    1.0000000E+03     7.1538755E-04    2.1150447E-03     4.7534704E-06     1.3289218E-02
      0.0000      1.0000000E+25    1.1000000E+03     6.9128847E-04    2.3003045E-03     4.9956790E-06     1.4453240E-02
      0.0000      1.0000000E+25    1.2000000E+03     6.6557357E-04    2.4782508E-03     5.1819258E-06     1.5571309E-02
      0.0000      1.0000000E+25    1.3000000E+03     6.3839869E-04    2.6482874E-03     5.3113751E-06     1.6639681E-02
      0.0000      1.0000000E+25    1.4000000E+03     6.0992178E-04    2.8098275E-03     5.3839830E-06     1.7654667E-02
      0.0000      1.0000000E+25    1.5000000E+03     5.8030152E-04    2.9622904E-03     5.4004658E-06     1.8612620E-02
      0.0000      1.0000000E+25    1.6000000E+03     5.4969558E-04    3.1050979E-03     5.3622543E-06     1.9509905E-02
```

Listing 10-3 Output from Optimization of FSW Airplane (Continued)

```
0                                                      FLUTTER  SUMMARY
                    CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = ASYMMETRIC
     POINT =     4     MACH NUMBER =  0.9000     DENSITY RATIO =  1.0000E+00     METHOD = PK

     KFREQ          1./KFREQ         VELOCITY           DAMPING          FREQUENCY           COMPLEX   EIGENVALUE
      0.0365       2.7426459E+01    1.0000000E+03    -2.5634569E-01    1.1605942E+00    -9.3466565E-01     7.2922282E+00
      0.0365       2.7432918E+01    1.1000000E+03    -2.5598542E-01    1.2763530E+00    -1.0264456E+00     8.0195625E+00
      0.0364       2.7440084E+01    1.2000000E+03    -2.5558781E-01    1.3920215E+00    -1.1177275E+00     8.7463289E+00
      0.0364       2.7447985E+01    1.3000000E+03    -2.5515199E-01    1.5075892E+00    -1.2084588E+00     9.4724622E+00
      0.0364       2.7456650E+01    1.4000000E+03    -2.5467701E-01    1.6230452E+00    -1.2985845E+00     1.0197894E+01
      0.0364       2.7466114E+01    1.5000000E+03    -2.5416180E-01    1.7383778E+00    -1.3880475E+00     1.0922550E+01
      0.0364       2.7476413E+01    1.6000000E+03    -2.5360523E-01    1.8535746E+00    -1.4767880E+00     1.1646353E+01
0                                                      FLUTTER  SUMMARY
                    CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = ASYMMETRIC
     POINT =     5     MACH NUMBER =  0.9000     DENSITY RATIO =  1.0000E+00     METHOD = PK

     KFREQ          1./KFREQ         VELOCITY           DAMPING          FREQUENCY           COMPLEX   EIGENVALUE
      0.0648       1.5427493E+01    1.0000000E+03    -7.0650252E-01    2.0632639E+00    -4.5795032E+00     1.2963870E+01
      0.0691       1.4480438E+01    1.1000000E+03    -6.9623436E-01    2.4180268E+00    -5.2889131E+00     1.5192910E+01
      0.0750       1.3337846E+01    1.2000000E+03    -6.7923248E-01    2.8638196E+00    -6.1110238E+00     1.7993909E+01
      0.0840       1.1897818E+01    1.3000000E+03    -6.4633439E-01    3.4779726E+00    -7.0620908E+00     2.1852747E+01
      0.1018       9.8209184E+00    1.4000000E+03    -5.5150281E-01    4.5375985E+00    -7.8618304E+00     2.8510572E+01
      0.1104       9.0589467E+00    1.5000000E+03    -1.3492491E+00    5.2706440E+00    -2.2341158E+01     3.3116433E+01
      0.0887       1.1277061E+01    1.6000000E+03    -2.1653969E+00    4.5162107E+00    -3.0722855E+01     2.8376188E+01
0                                                      FLUTTER  SUMMARY
                    CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = ASYMMETRIC
     POINT =     6     MACH NUMBER =  0.9000     DENSITY RATIO =  1.0000E+00     METHOD = PK

     KFREQ          1./KFREQ         VELOCITY           DAMPING          FREQUENCY           COMPLEX   EIGENVALUE
      0.2580       3.8759407E+00    1.0000000E+03    -1.3266551E-02    8.2124551E+00    -3.4227951E-01     5.1600377E+01
      0.2347       4.2607273E+00    1.1000000E+03    -1.4623583E-02    8.2178663E+00    -3.7753980E-01     5.1634377E+01
      0.2153       4.6446422E+00    1.2000000E+03    -1.6010263E-02    8.2239244E+00    -4.1364468E-01     5.1672441E+01
      0.1989       5.0275947E+00    1.3000000E+03    -1.7431662E-02    8.2306327E+00    -4.5073564E-01     5.1714591E+01
      0.1849       5.4094957E+00    1.4000000E+03    -1.8892761E-02    8.2379924E+00    -4.8895252E-01     5.1760833E+01
      0.1727       5.7902490E+00    1.5000000E+03    -2.0397770E-02    8.2460154E+00    -5.2841692E-01     5.1811243E+01
      0.1621       6.1697533E+00    1.6000000E+03    -2.1950936E-02    8.2547193E+00    -5.6925288E-01     5.1865931E+01
0                                                      FLUTTER  SUMMARY
                    CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = ASYMMETRIC
     POINT =     7     MACH NUMBER =  0.9000     DENSITY RATIO =  1.0000E+00     METHOD = PK

     KFREQ          1./KFREQ         VELOCITY           DAMPING          FREQUENCY           COMPLEX   EIGENVALUE
      0.3340       2.9939361E+00    1.0000000E+03    -1.6405818E-01    1.0631819E+01    -5.4796819E+00     6.6801692E+01
      0.2917       3.4278882E+00    1.1000000E+03    -2.0509417E-01    1.0214478E+01    -6.5814162E+00     6.4179456E+01
      0.2525       3.9605471E+00    1.2000000E+03    -2.6046042E-01    9.6444218E+00    -7.8916498E+00     6.0597689E+01
      0.2136       4.6819327E+00    1.3000000E+03    -3.3732085E-01    8.8382913E+00    -9.3661558E+00     5.5532622E+01
      0.1679       5.9546627E+00    1.4000000E+03    -4.7222910E-01    7.4837797E+00    -1.1102572E+01     4.7021975E+01
      0.1177       8.4969071E+00    1.5000000E+03    -1.2617426E-03    5.6192780E+00    -2.2274150E-02     3.5306965E+01
      0.1115       8.9692107E+00    1.6000000E+03     3.2320719E-01    5.6782680E+00     5.7656299E+00     3.5677610E+01
                    CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = ASYMMETRIC
     POINT =     8     MACH NUMBER =  0.9000     DENSITY RATIO =  1.0000E+00     METHOD = PK

     KFREQ          1./KFREQ         VELOCITY           DAMPING          FREQUENCY           COMPLEX   EIGENVALUE
      0.6022       1.6606137E+00    1.0000000E+03    -2.9345059E-02    1.9168208E+01    -1.7671213E+00     1.2043740E+02
      0.5478       1.8256067E+00    1.1000000E+03    -3.1333158E-02    1.9179426E+01    -1.8879463E+00     1.2050789E+02
      0.5025       1.9901963E+00    1.2000000E+03    -3.3152920E-02    1.9192672E+01    -1.9989739E+00     1.2059112E+02
      0.4642       2.1543462E+00    1.3000000E+03    -3.4846735E-02    1.9207816E+01    -2.1027612E+00     1.2068627E+02
      0.4314       2.3180426E+00    1.4000000E+03    -3.6512490E-02    1.9224575E+01    -2.2052005E+00     1.2079157E+02
      0.4030       2.4813193E+00    1.5000000E+03    -3.8233089E-02    1.9242378E+01    -2.3112557E+00     1.2090343E+02
      0.3782       2.6441146E+00    1.6000000E+03    -4.0023205E-02    1.9261488E+01    -2.4218741E+00     1.2102350E+02

               ***** NORMAL CONVERGENCE CRITERIA SATISFIED ***** (HARD CONVERGENCE DECISION LOGIC)

               ***************************************************************************************
                                CONVERGENCE ACHIEVED BASED ON THE FOLLOWING CRITERIA
                                         (HARD CONVERGENCE DECISION LOGIC)

                      RELATIVE CHANGE IN OBJECTIVE        1.5547E-04  MUST BE LESS THAN   1.0000E-03
                OR    ABSOLUTE CHANGE IN OBJECTIVE        2.5899E+00  MUST BE LESS THAN   1.0000E-20
                                              --- AND ---
                      MAXIMUM CONSTRAINT VALUE           -7.9890E-03  MUST BE LESS THAN   5.0000E-03
                                        (CONVERGENCE TO A FEASIBLE DESIGN)
                                              --- OR ---
                      MAXIMUM OF RELATIVE PROP. CHANGES   2.4998E-01  MUST BE LESS THAN   1.0000E-03
                AND   MAXIMUM OF RELATIVE D.V. CHANGES    2.4998E-01  MUST BE LESS THAN   1.0000E-03
                               (CONVERGENCE TO A BEST COMPROMISE INFEASIBLE DESIGN)
               ***************************************************************************************
```

Listing 10-3 Output from Optimization of FSW Airplane (Continued)

```
                                  ***************************************************************
                                  S U M M A R Y    O F    D E S I G N    C Y C L E    H I S T O R Y
                                  ***************************************************************

                                                   (HARD CONVERGENCE ACHIEVED)

                                      NUMBER OF FINITE ELEMENT ANALYSES COMPLETED          7
                                      NUMBER OF OPTIMIZATIONS W.R.T. APPROXIMATE MODELS    6

                                               OBJECTIVE AND MAXIMUM CONSTRAINT HISTORY
          ---------------------------------------------------------------------------------------------------------------
                          OBJECTIVE FROM          OBJECTIVE FROM          FRACTIONAL ERROR          MAXIMUM VALUE
            CYCLE           APPROXIMATE               EXACT                      OF                       OF
            NUMBER         OPTIMIZATION             ANALYSIS              APPROXIMATION              CONSTRAINT
          ---------------------------------------------------------------------------------------------------------------

            INITIAL                                1.605500E+04                                        1.460522E+01

                  1          1.645750E+04          1.645750E+04           -8.178959E-15             8.654671E+00

                  2          1.694125E+04          1.694125E+04            6.291908E-14             1.565344E+00

                  3          1.674741E+04          1.674741E+04            2.107095E-14             3.512834E-02

                  4          1.664890E+04          1.664890E+04           -1.966604E-14             2.183912E-01

                  5          1.665931E+04          1.665931E+04            2.183751E-16            -8.041282E-03

                  6          1.665672E+04          1.665672E+04           -2.184091E-16            -7.989032E-03
          ---------------------------------------------------------------------------------------------------------------
1    EXAMPLE HA200B: 30 DEG FWD SWEPT WING WITH CANARD AND  HA200B          JULY   9, 2019  MSC Nastran  7/ 8/19   PAGE  1408
      DEMONSTRATION OF AEROELASTIC OPTIMIZATION
0
                                                        DESIGN VARIABLE HISTORY
 ------------------------------------------------------------------------------------------------------------------------------
---
  INTERNAL |   EXTERNAL    |              |
   DV. ID. |    DV. ID.    |    LABEL     |   INITIAL    :      1       :      2       :      3       :      4       :      5       :
 ------------------------------------------------------------------------------------------------------------------------------
---
         1 |        10    |  PBAR101    |  1.0000E+00 :  1.2000E+00 :  1.4400E+00 :  1.7224E+00 :  2.0310E+00 :  2.0394E+00 :
         2 |        20    |  PBAR102    |  1.0000E+00 :  1.2000E+00 :  1.4400E+00 :  1.1520E+00 :  9.2201E-01 :  9.2741E-01 :
         3 |        30    |  PBAR103    |  1.0000E-01 :  1.5000E-01 :  2.2500E-01 :  2.6239E-01 :  3.1143E-01 :  2.6339E-01 :
 ------------------------------------------------------------------------------------------------------------------------------
---
  INTERNAL |   EXTERNAL    |              |
   DV. ID. |    DV. ID.    |    LABEL     |       6       :       7      :       8      :       9      :      10      :      11      :
 ------------------------------------------------------------------------------------------------------------------------------
---
         1 |        10     |  PBAR101     |   2.0332E+00 :
         2 |        20     |  PBAR102     |   9.3102E-01 :
         3 |        30     |  PBAR103     |   1.9755E-01 :
 *** USER INFORMATION MESSAGE 6464 (DOM12E)
     RUN TERMINATED DUE TO HARD CONVERGENCE TO AN OPTIMUM AT CYCLE NUMBER =        6.
```

References

The references below are all cited in the text of this guide. These are listed alphabetically by the first author. In the case of multiple references to the same author, the references are listed chronologically by year. For multiple references to the same author in the same year, letters in alphabetical order are appended to the year.

1. **Albano, E., and Rodden, W. P. (1969).** A Doublet-Lattice Method for Calculating Lift Distributions on Oscillating Surfaces in Subsonic Flows. *AIAA J.*, Vol. 7, pp. 279-285, p. 2192.
2. **Anon. (1961).** Proceedings of Symposium on Aerothermoelasticity. Air Force Systems Command, ASD Technical Report 61-645.
3. **Anon. (1971).** "Modal Flutter Analysis Study; Vol. IV, Aero-Servo-Elastic Stability Analysis Program: PASES," Rpt. No. SD15204R, Hughes Aircraft Company.
4. **Appa, Kari,** Finite-Surface Spline *Journal of Aircraft*, Vol 26, No. 5, May 1989. pp. 495-496
5. **Ashley, H., and Zartarian, G. (1956).** Piston Theory - A New Aerodynamic Tool for the Aeroelastician. *J. Aero. Sci.*, Vol. 23, pp. 1109-1118.
6. **Beckert, A. and H. Wendland**, Multivariate Interpolation for Fluid-Structure-Interaction Problems Using Radial Basis Functions, *Aerosp. Sci. Technol.* 00 (2001), pp. 1-11.
7. **Bisplinghoff, R. L. (1956).** Some Structural and Aeroelastic Considerations of High Speed Flight. *J. Aero. Sci.*, Vol. 23, pp. 289-329, 367.
8. **Bisplinghoff, R. L., Ashley, H., and Halfman, R. L. (1955).** *Aeroelasticity*. Reading: Addison-Wesley Publishing Company.
9. **Bryan, G. H. (1911).** *Stability in Aviation*. London: MacMillan Company.
10. **Budiansky, B., and Mayers, J. (1956).** Influence of Aerodynamic Heating on the Effective Torsional Stiffness of Thin Wings. *J. Aero. Sci.*, Vol. 23, pp. 1081-1093, 1108.
11. **Chen, P. C., and Liu, D. D. (1985).** A Harmonic Gradient Method for Unsteady Supersonic Flow Calculations. *J. Aircraft*, Vol. 22, pp. 371-379.
12. **Desmarais, R. N., and Bennett, R. M. (1974).** An Automated Procedure for Computing Flutter Eigenvalues. *J. Aircraft*, Vol. 11, pp. 75-80.
13. **Donato, V. W., and Huhn, C. R., Jr. (1968).** Supersonic Unsteady Aerodynamics for Wings with Trailing-edge Control Surfaces and Folded Tips. Air Force Flight Dynamics Laboratory Report No. AFFDL-TR-68-30.
14. **Etkin, B. (1972).** *Dynamics of Atmospheric Flight*. New York: John Wiley & Sons.
15. **Finck, R. D., and Hoak, D. E. (1976).** USAF Stability and Control DATCOM. Air Force Flight Dynamics Laboratory, Flight Controls Division.
16. **Frazer, R. A., and Duncan, W. J. (1928).** The Flutter of Aeroplane Wings. British A.R.C., R. & M. 1155.
17. **Friedman, I.P., Vosteen, L.F., Cooper, M.J., Gold, R.R., and Reed, W.H.,III (1988).** Assessment of Thermoelastic Analysis and Testing Applicable to the National Aero-Space Plane. NASP Contractor Report 1017.
18. **Giesing, J. P., Kalman, T. P., and Rodden, W. P. (1971).** Subsonic Unsteady Aerodynamics for General Configurations; Part I, Vol. I - Direct Application of the Nonplanar Doublet-Lattice Method. Air Force Flight Dynamics Laboratory Report No. AFFDL-TR-71-5, Part I, Vol. I.

19. **Giesing, J. P., Kalman, T., and Rodden, W. P. (1972a)**. Subsonic Unsteady Aerodynamics for General Configurations, Part II, Volume I - Application of the Doublet-Lattice-Method and the Method of Images to Lifting-Surface/Body Interference. Air Force Flight Dynamics Laboratory Report No. AFFDL-TR-71-5, Part II, Vol. I.

20. **Giesing, J. P., Kalman, T. P., and Rodden, W. P. (1972b)**. Subsonic Unsteady Aerodynamics for General Configurations; Part II, Volume II - Computer Program N5KA. Air Force Flight Dynamics Laboratory Report No. AFFDL-TR-71-5, Part II, Vol. II.

21. **Giesing, J. P., Kalman, T. P., and Rodden, W. P. (1972c)**. Subsonic Steady and Oscillatory Aerodynamics for Multiple Interfering Wings and Bodies. *J. Aircraft*, Vol. 9, pp. 693-702.

22. **Giesing, J. P., Kalman, T. P., and Rodden, W. P. (1976)**. Correction Factor Techniques for Improving Aerodynamic Prediction Methods. NASA CR 144967, May 1976.

23. **Harder, R. L., and Desmarais, R. N. (1972a)**. Interpolation Using Surface Splines. *J. Aircraft*, Vol. 9, pp. 189-191.

24. **Harder, R. L, and Desmarais, R. N. (1972b)**. Reply by Authors to W. P. Rodden, J. A. McGrew, and T. P. Kalman. *J. Aircraft*, Vol. 9, p. 871.

25. **Harder, R. L., MacNeal, R. H., and Rodden, W. P. (1971)**. A Design Study for the Incorporation of Aeroelastic Capability into NASTRAN. NASA CR-111918.

26. **Hassig, H. J. (1971)**. An Approximate True Damping Solution of the Flutter Equation by Determinant Iteration. *J. Aircraft*. Vol. 8, pp. 885-889.

27. **Hedgepeth, J. M. (1957)**. Flutter of Rectangular Simply Supported Panels at High Supersonic Speeds. *J. Aero. Sci.*, Vol. 24, pp. 563-573, 586.

28. **Johnson, E. H., and Venkayya, V. B., (1988).** Automated Structural Optimization System (ASTROS), Volume 1. Theoretical Manual, AFWAL-TR-88,3028, Volume 1.

29. **Johnson, E. H., and Reymond, M. A., Multidisciplinary Aeroelastic Analysis and Design Using MSC/NASTRAN (1991)**. Proceedings of the AIAA/ASME/ASCE/AHS/ASG 32nd Structures, Structural Dynamics, and Materials Conference AIAA-91-1097-CP, Baltimore, MD.

30. **Komzsik, L. (1993)** *MSC/NASTRAN Numerical Methods User's Guide*. The MacNeal-Schwendler Corporation.

31. **Küssner, H. G., and Schwarz, I. (1940)**. Der schwingenden Flugel mit aerodynamisch ausgeglichenem Ruder. Luftfahrtforschung, Vol. 17, pp. 337-354; translated as The Oscillating Wing with Aerodynamically Balanced Elevator, NACA TM-991.

32. **Lawrence, A. J., and Jackson, P. (1970)**. Comparison of Different Methods of Assessing the Free Oscillatory Characteristics of Aeroelastic Systems. British A.R.C. C.P. No. 1084.

33. **Liu, D. D., James, D. K., Chen, P. C., and Pototzky, A. S. (1991)**. Further Studies of Harmonic Gradient Method for Supersonic Aeroelastic Applications. *J. Aircraft*, Vol. 28, pp. 598-605.

34. **Moler C. and Stewart G.W. (1973)**, "An Algorithm for Generalized Matrix Eigenvalue Problems," SIAM J. Numerical Analysis, 10:241-256.

35. **Moore, M. T., and Andrew, L. V. (1965)**. Unsteady Aerodynamics for Advanced Configurations, Part IV - Application of the Supersonic Mach Box Method to Intersecting Planar Lifting Surfaces. Air Force Flight Dynamics Laboratory Report, No. FDL-TDR-64-152, Part IV.

36. **Neill, D. N., Johnson, E. H., and Canfield, R. A., (1987).** ASTROS - A Multidisciplinary Automated Structural Design Tool. Proceedings of the AIAA/ASME/ASCE/AHS/ASC 28th Structures, Structural Dynamics and Materials Conference. AIAA-87-0713-CP, Monterey, California.
37. **Pendleton, E. W., French, M., and Noll, T. E. (1987).** A Comparison of Flutter Analyses for a 45° Swept Transonic Model. Proceedings of the AIAA Design, Systems & Operations Meeting, St. Louis, MO.
38. **Pines, S., Dugundji, J., and Neuringer, J. (1955).** Aerodynamic Flutter Derivatives for a Flexible Wing with Supersonic and Subsonic Edges. *J. Aero. Sci.*, Vol. 22, pp. 693-700.
39. **Reymond, M. and Miller, M. P. (1994).** *MSC/NASTRAN Quick Reference Guide*. The MacNeal-Schwendler Corporation.
40. **Rodden, W. P. (1959a).** A Matrix Approach to Flutter Analysis. Institute of the Aeronautical Sciences, Fairchild Fund Paper No. FF-23.
41. **Rodden, W. P. (1959b).** Further Remarks on "Matrix Interpolation of Flexibility Influence Coefficients." *J. Aero. Sci.*, Vol. 13, p. 760.
42. **Rodden, W. P. (1977).** Comment on "Flutter of Flat Finite Element Panels in a Supersonic Potential Flow." *AIAA J.*, Vol. 15, pp. 755-756.
43. **Rodden, W. P. (ed.) (1987).** MSC/NASTRAN Handbook for Aeroelastic Analysis. The MacNeal-Schwendler Corp., Report MSR-57.
44. **Rodden, W. P., and Bellinger, E. D. (1982a).** Aerodynamic Lag Functions, Divergence, and the British Flutter Method. *J. Aircraft*, Vol. 19, pp. 596-598.
45. **Rodden, W. P., and Bellinger, E. D. (1982b).** Unrestrained Aeroelastic Divergence in a Dynamic Stability Analysis. *J. Aircraft*, Vol. 19, pp. 796-797.
46. **Rodden, W. P., Bellinger, E. D., and Giesing, J. P. (1984).** Errata and Addenda to "Application of Oscillatory Aerodynamic Theory to Estimation of Dynamic Stability Derivatives." *J. Aircraft*, Vol. 21, pp. 93-94.
47. **Rodden, W. P., Farkas, E. F., Malcom, H. A., and Kliszewski, A. M. (1962).** Aerodynamic Influence Coefficients from Piston Theory: Analytical Development and Computational Procedure. Aerospace Corp., Report No. TDR-169(3230-11)TN-2.
48. **Rodden, W. P., and Giesing, J. P. (1970).** Application of Oscillatory Aerodynamic Theory to Estimation of Dynamic Stability Derivatives. *J. Aircraft*, Vol. 7, pp. 272-275.
49. **Rodden, W. P., Giesing, J. P., and Kalman, T. P. (1972).** Refinement of the Nonplanar Aspects of the Subsonic Doublet-Lattice Lifting Surface Method. *J. Aircraft*, Vol. 9, pp. 69-73.
50. **Rodden, W. P., Harder, R. L., and Bellinger, E. D. (1979).** Aeroelastic Addition to NASTRAN. NASA Contractor Report 3094.
51. **Rodden, W. P., and Love, J. R. (1985).** Equations of Motion of a Quasisteady Flight Vehicle Utilizing Restrained Static Aeroelastic Characteristics. *J. Aircraft*, Vol. 22, pp. 802-809.
52. **Rodden W. P., McGrew, J. A., and Kalman, T.P. (1972).** Comment on "Interpolation Using Surface Splines" *J. Aircraft*, Vol. 9, pp. 869-871.

Main Index

53. **Rodden, W. P. and Harder, R. L. (1975).** Flutter Analysis with Active Controls, Proceedings of MSC/NASTRAN Users' Conference, Pasadena, CA.
54. **Rodden, W. P., and Revell, J. D. (1962).** The Status of Unsteady Aerodynamic Influence Coefficients. Institute of the Aeronautical Sciences, Fairchild Fund Paper No. FF-33.
55. **Schmitt, A. F. (1956).** A Least Squares Matrix Interpolation of Flexibility Influence Coefficients. *J. Aero. Sci.*, Vol. 10, p. 980.
56. **Smilg, B., and Wasserman, L. S. (1942).** Application of Three-Dimensional Flutter Theory to Aircraft Structures. Army Air Force Tech. Rpt. 4798.
57. **Taylor, J. (ed.). (1965).** *Manual on Aircraft Loads*. AGARDograph 83, Pergamon Press.
58. **Theodorsen, T. (1935).** General Theory of Aerodynamic Instability and the Mechanism of Flutter. NACA Report 496.
59. **Timoshenko S, Young D. H. and Weaver W., Jr. (1974).** *Vibration problems in engineering* New York: Wiley, 4th Edition pp. 474.
60. **Tuovila, W.J., and McCarty, J. L., (1955)** Experimental Flutter Results for Cantilever Wing Models at Mach Numbers Up to 3.0, NACA RM L55E11.
61. **Turner, M.J., Dill, E.H., Martin, H.C., and Melosh, R.J. (1960).** Large Deflections of Structures Subjected to Heating and External Loads. *J. Aero/Space Sci*., Vol. 27, pp. 97-106, 127.
62. **Vanderplaats, G. N. (1984).** Numerical Optimization Techniques for Engineering Design with Applications. New York: McGraw-Hill Book Company.
63. **Van Dyke, M. D. (1952).** A Study of Second-Order Supersonic Flow Theory. NACA Report 1081.
64. **Yates, E. C., Jr., and Bennett, R. M. (1963).** Use of Aerodynamic Parameters from Nonlinear Theory in Modified-Strip-Analysis Flutter Calculations for Finite-Span Wings at Supersonic Speeds, NASA TND-1824.
65. **Zartarian, G. (1956).** Theoretical Studies on the Prediction of Unsteady Airloads on Elastic Wings; Part II - Rules for Application of Oscillatory Supersonic Aerodynamic Influence Coefficients. Wright Air Development Center, WADC Technical Report 56-97, Part II.
66. **Zartarian, G., and Hsu, P. T. (1955).** Theoretical Studies on the Prediction of Unsteady Airloads on Elastic Wings; Part I - Investigations on the Use of Oscillatory Supersonic Aerodynamic Influence Coefficients. Wright Air Development Center, WADC Technical Report 56-97, Part I.

Bibliography

Bibliography of Aeroelasticity and Unsteady Aerodynamics

It contains textbook references to the fundamentals of aerodynamic/structural interaction. The available literature on the structural, dynamic, and aerodynamic aspects of aeroelasticity is extensive, and it is assumed that the user has some familiarity with these topics. The literature dedicated exclusively to aeroelasticity is also extensive.

However, the following list of textbook references on aeroelasticity and unsteady aerodynamics can be recommended to the user for guidance on the fundamentals of aerodynamic/structural interaction. Two optimization references are also cited to provide an introduction to the wide range of literature in this field. All references are listed in chronological order.

1. Freberg, C. R., and Kemler, E. N. (1944). *Aircraft Vibration and Flutter*. New York: John Wiley & Sons.
2. Perkins, C. D., and Hage, R. E. (1949). *Airplane Performance, Stability and Control*. New York: John Wiley & Sons.
3. Scanlan, R. H., and Rosenbaum, R. (1951). *Introduction to the Study of Aircraft Vibration and Flutter*. New York: The Macmillan Company.
4. Bisplinghoff, R. L., Ashley, H., and Halfman, R. L. (1955). *Aeroelasticity.* Reading: Addison-Wesley Publishing Company.
5. Fung, Y. C. (1955). *An Introduction to the Theory of Aeroelasticity*. New York: John Wiley & Sons.
6. Den Hartog, J. P. (1956). *Mechanical Vibrations*. New York: McGraw-Hill Book Company, 4th ed.
7. Garrick, I. E. (1957) "Nonsteady Wing Characteristics," Sect. F., Vol. VII, of *High Speed Aerodynamics and Jet Propulsion*. Princeton N.J.: Princeton University Press.
8. Abramson, H. N. (1958). *An Introduction to the Dynamics of Airplanes*. New York: The Ronald Press Company.
9. Miles, J. W. (1958). *The Potential Theory of Unsteady Supersonic Flow*. Cambridge: The University Press.
10. Many authors, *Manual on Aeroelasticity*, Vols. I-VII, Advisory Group for Aerospace Research and Development (AGARD), beginning in 1959 with continual updating.
11. Landahl, M. T. (1961). *Unsteady Transonic Flow*. Oxford: Pergamon Press.
12. Bisplinghoff, R. L., and Ashley, H. (1962). *Principles of Aeroelasticity.* New York: John Wiley & Sons.
13. Ashley, H., and Landahl, M. (1965). *Aerodynamics of Wings and Bodies*. Reading: Addison-Wesley Publishing Company.
14. Petre, A. (1966). *Teoria Aeroelasticitiatii-Statica*. Bucharest: Editura Academiei Republicii Socialiste Romania.
15. Garrick, I. E. (1969). *Aerodynamic Flutter*. New York: AIAA Selected Reprint Series, Vol. V, 1969.
16. Ashley, H., and Rodden, W. P. (1972). "Wing-Body Interaction," pp. 431-471, *Annual Review of Fluid Mechanics*. Palo Alto: Annual Reviews, Inc., Vol. 4.
17. Etkin, B. (1972). *Dynamics of Atmospheric Flight*. New York: John Wiley & Sons.

18. Petre, A. (1973). *Teoria Aeroelasticitiatii-Fenomene Dinamice Periodice*. Bucharest: Editura Academici Republicii Socialiste Romania.

19. Försching, H. W. (1974). *Grundlagen der Aeroelastik*. Berlin: Springer-Verlag.

20. Blevins, R. D. (1977). *Flow-induced Vibration*. New York: Van Nostrand Reinhold Company.

21. Vanderplaats, G. N. (1984). *Numerical Optimization Techniques for Engineering Design with Applications*. New York: McGraw-Hill Book Company.

22. Haftka, R. T., and Kamat, M. P. (1985). *Elements of Structural Optimization*. The Hague: Martinus Nijhoff Publishers.

23. Hoblit, F. M. (1988). *Gust Loads on Aircraft: Concepts and Applications*. Washington, D.C.: American Institute of Aeronautics and Astronautics.

24. Dowell, E. H., Curtiss, H. C., Jr., Scanlan, R. H., and Sisto, F. (1990). *A Modern Course in Aeroelasticity*. Alphen aan der Rijn, The Netherlands: Sijthoff & Noordhoff, 2nd ed.

25. Appa, K., Constant Pressure Panel Method for Supersonic Unsteady Aiorloads Analysis, Journal of Aircraft, vol 24, October 1987, pp 696-702 Appa, K. and Smith, M.J.C., Evaluation of the Constant Pressure Panel Method (CPM) for Unsteady Air Loads Prediction, AIAA-88-2282, AIAA/ASME/ASCE/AHS 29th Structure, Structural Dynamics and Materials Conference, Williamsburg, Virginia, April 1988.

Bibliography of MSC Nastran Applications

This bibliography is a summary of MSC Nastran-related papers dealing with solutions to aeroelastic and aerodynamic problems. They are excerpted from the *MSC Nastran Bibliography* (2nd ed.) and are gathered from various MSC Users' Conferences, other NASTRAN User's Colloquia, and a search of the general engineering literature.

AEROELASTICITY/AERODYNAMICS

- Armand, Sasan C.; Liao, Mei-Hwa; Morris, Ronald W. ***A Transient Plasticity Study and Low Cycle Fatigue Analysis of the Space Station Freedom Photovoltaic Solar Array Blanket,*** The MSC 1990 World Users Conf. Proc., Vol. I, Paper No. 19, March, 1990.
- Bhatia, Kumar G.; Nagaraja, K. S. ***Transonic and Density Effect Investigations,*** Flutter Parametric Studies of Cantilevered Twin-Engine-Transport Type Wing with and without Winglet, Vol. II, September, 1984, (NASA CR-172410).
- Boroughs, Robert R. ***Development of the LEARJET 28/29 Wing Using NASTRAN Analysis,*** Eighth NASTRAN Users' Colloq., pp. 11-32, October, 1979, (NASA CP-2131).
- Briggs, Hugh C.; Chrisinger, Lance E. ***A New Capability for Elastic Aircraft Airloads via NASTRAN,*** Tenth NASTRAN Users' Colloq., pp. 165-186, May, 1982, (NASA CP-2249).
- Cifuentes, Arturo; Bock, Timothy L.; Coppolino, Robert N. ***A Finite Element Technique for Tape-Head Interaction Problems in High Speed Recording: The Steady-State Case,*** The 1989 MSC World Users Conf. Proc., Vol. I, Paper No. 24, March, 1989.

- Clark, Wm. B. ***Gulfstream Experience Using NASTRAN Solution 76 for Lateral Gust Loads Analysis of the G-IV Airplane,*** Proc. of the MSC/NASTRAN Aeroelasticity Users Conf., Paper No. 1, October, 1989.
- Climent, Hector; Johnson, Erwin H. ***Aeroelastic Optimization Using MSC/NASTRAN***, Int. Forum on Aeroelasticity and Structural Dynamics 1993, May, 1993.
- Crimaldi, J. P.; Britt, R. T.; Rodden, W. P. ***Response of the USAF/Northrop B-2 Aircraft to Nonuniform Spanwise Atmospheric Turbulence,*** Proc. of the 32nd AIAA/ASME/ ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conf., Paper No. 91-1048, April, 1991.
- Crittenden, J. B.; Weisshaar, T. A.; Johnson, E. H.; Rutkowski, M. J. ***Aeroelastic Stability Characteristics of an Oblique-Wing Aircraft,*** J. of Aircraft, Vol. 15, No. 7, pp. 429-434, July, 1978.
- Deerhake, Allen. ***A Critique of the MSC/NASTRAN Flutter Analysis Capability,*** Proc. of the MSC/NASTRAN Users' Conf., March, 1979.
- Desy, Philippe; Perron, Claude. ***Loads Balancing Technique Using MSC/NASTRAN Results,*** The MSC 1991 World Users' Conf. Proc., Vol. I, Paper No. 16, March, 1991.
- Doggett, Robert V.; Harder, Robert L. ***Subsonic Flutter Analysis Addition to NASTRAN,*** NASTRAN: Users' Exper., pp. 507-530, September, 1973, (NASA TM X-2893).
- Doggett, Robert V.; Cunningham, Herbert J. Jr. ***Some Applications of the NASTRAN Level 16 Subsonic Flutter Analysis Capability,*** NASTRAN: Users' Exper., pp. 495-512, October, 1976, (NASA TM X-3428).
- Eversman, W.; Tewari, A. ***A Reduced Cost Rational-Function Approximation for Unsteady Aerodynamics,*** Proc. of the MSC/NASTRAN Aeroelasticity Users Conf., Paper No. 11, October, 1989.
- Geyer, A.; Schweiger, W. ***Aeroelastic and Stress Analysis of the CHIWEC Chinese Wind Energy Converter Using MSC/NASTRAN,*** Proc. of the MSC/NASTRAN Eur. Users' Conf., April, 1985.
- Harder, R. L.; MacNeal, R. H.; Rodden, W. P. ***A Design Study for the Incorporation of Aeroelastic Capability into NASTRAN,*** National Aeronautics and Space Administration, May, 1971, (NASA CR-111918).
- Harder, R. L.; MacNeal, R. H.; Rodden, W. P. ***A Study of a Finite Element Method to Calculate Oscillatory Supersonic Lift Distributions Using the Acceleration Potential Kernel,*** National Aeronautics and Space Administration, August, 1971, (NASA CR-111998).
- Harder, Robert L.; MacNeal, Richard H.; Doggett, Robert V. Jr. ***A Design Study for the Incorporation of Aeroelastic Capability,*** NASTRAN: Users' Exper., pp. 779-796, September, 1971, (NASA TM X-2378).
- Heinze, P.; Schierenbeck, D.; Niemann, L. ***Structural Optimization in View of Aeroelastic Constraints Based on MSC/NASTRAN FE-Calculation,*** Proc. of the Sixteenth MSC Eur. Users' Conf., Paper No. 15, September, 1989.
- Hsu, Lu-Jiin; Chiou, Hua-Tzong; Chen, Kuo-Her. ***A Study of the Deformation Behavior of Wing for Composite Material,*** The 2nd Annual MSC Taiwan Users Conf., Paper No. 4, October, 1990.
- Hwang, Jyh-Yeon. ***A Study of the Structural Dynamic Characteristics Under the Aeroelastic Interaction***, The 4th MSC Taiwan Users' Conf., Paper No. 10, November, 1992, in Chinese.

- Jew, Howard. ***Delta Wing Flutter Based on Doublet Lattice Method in NASTRAN,*** NASTRAN: Users' Exper., pp. 603-614, September, 1975, (NASA TM X-3278).
- Johnson, Erwin H. ***Further Development of the Aeroelasticity Capability in MSC/NASTRAN,*** Proc. of the MSC/NASTRAN Aeroelasticity Users Conf., Paper No. 8, October, 1989.
- Johnson, E. H.; Rodden, W. P. ***Ongoing Development of the MSC/NASTRAN Aeroelastic Capability,*** Proc. of the 17th MSC Eur. Users' Conf., Paper No. 10, September, 1990.
- Johnson, Erwin; Nagendra, Gopal; Reymond, Michael. ***Addition of Aeroelasticity to the MSC/NASTRAN Multidisciplinary Analysis and Design Capability,*** The MSC 1991 World Users' Conf. Proc., Vol. I, Paper No. 7, March, 1991.
- Karpel, Mordechay; Presente, Eyal. ***Structural Dynamic Loads in Response to Impulsive Excitation***, Int. Forum on Aeroelasticity and Structural Dynamics 1993, May, 1993.
- Kooj, B.; Wijker, J. ***Air Effects on the Dynamic Behaviour of Stowed Solar Array Wings,*** Proc. of the Fifteenth MSC/NASTRAN Eur. Users' Conf., October, 1988.
- Lecce, Leonardo; Marulo, Francesco; D'Amato, Ciro Angelo; Verde, Giuseppe. ***Aeroelastic Behaviour on an All-Movable Horizontal Tail of a General Aviation Twin-Engine Aircraft***, Int. Forum on Aeroelasticity and Structural Dynamics 1993, May, 1993.
- Lee, In; Miura, Hirokazu; Chargin, Mladen; Green, John. ***Static Aeroelastic Analysis for Generic Configuration Wing,*** Proc. of the MSC/NASTRAN Aeroelasticity Users Conf., Paper No. 2, October, 1989.
- Lee, Kuan S.; Miller, R. P.; Porada, T. W. ***An Application of MSC/NASTRAN Transfer Functions for Launch Vehicle Air-Loads Analysis,*** The MSC 1991 World Users' Conf. Proc., Vol. I, Paper No. 15, March, 1991.
- Lenselink, H. ***Aerodynamic Loading on a Thrust-Reverser,*** The MSC 1991 World Users' Conf. Proc., Vol. I, Paper No. 17, March, 1991.
- Lewis, A. P. ***A NASTRAN DMAP Procedure for Aeroelastic Design Sensitivity Analysis,*** Proc. of the 18th MSC Eur. Users' Conf., Paper No. 17, June, 1991.
- Lin, Hung-Hsi; Jhou, Jitai; Stearman, Ronald. ***Influence of Joint Fixity on the Structural Static and Dynamic Response of a Joined Wing Aircraft,*** Proc. of the MSC/NASTRAN Aeroelasticity Users Conf., Paper No. 9, October, 1989.
- Liu, D. D. ***ZONA Codes for Supersonic Aeroelastic Application,*** Proc. of the MSC/NASTRAN Aeroelasticity Users Conf., Paper No. 10, October, 1989.
- MacNeal, R. H.; Rodden, W. P. ***Requirements for the Addition of Aeroelastic Capability to NASTRAN,*** The MacNeal-Schwendler Corporation, Report No. MSR-21, March, 1970.
- Masse, Barnard; Pastorel, Henri. ***Stress Calculation for the Sandia 34-Meter Wind Turbine Using the Local Circulation Method and Turbulent Wind,*** The MSC 1991 World Users' Conf. Proc., Vol. II, Paper No. 53, March, 1991.
- McNamee, Martin J.; Zavareh, Parviz. ***Nonlinear Transient Analysis of a Shock Isolated Mechanical Fuse,*** The MSC 1990 World Users Conf. Proc., Vol. I, Paper No. 21, March, 1990.
- Mei, Chuh; Rogers, James L. Jr. ***Application of NASTRAN to Large Deflection Supersonic Flutter of Panels,*** NASTRAN: Users' Exper., pp. 67-98, October, 1976, (NASA TM X-3428).

Main Index

- Nakamura, Hitoshi; Ogaki, Ikuko. ***Flutter Simulation for Bridges,*** The MSC 1990 World Users Conf. Proc., Vol. I, Paper No. 20, March, 1990.
- Parthasarathy, Alwar. ***Force-Sum Method for Dynamic Stresses in MSC/NASTRAN Aeroelastic Analysis,*** The MSC 1991 World Users' Conf. Proc., Vol. I, Paper No. 8, March, 1991.
- Rodden, W. P.; Harder, R. L.; Bellinger, E. D. ***Aeroelastic Addition to NASTRAN,*** National Aeronautics and Space Administration, March, 1979, (NASA CR-3094).
- Rodden, W. P.; Bellinger, E. D. ***Aerodynamic Lag Functions, Divergence, and the British Flutter Method,*** J. of Aircraft, Vol. 19, No. 7, pp. 596-598, 1982.
- Rodden, W. P.; Bellinger, E. D. ***Unrestrained Aeroelastic Divergence in a Dynamic Stability Analysis,*** J. of Aircraft, Vol. 19, No. 9, pp. 796-797, 1982.
- Rodden, W. P.; Bellinger, E. D.; Giesing, J. P. ***Errata and Addenda to 'Application of Oscillatory Aerodynamic Theory to Estimation of Dynamic Stability Derivatives,'*** J. of Aircraft, Vol. 21, No. 1, pp. 93-94, 1984.
- Rodden, W. P.; Wilson, C. T.; Herting, D. N.; Bellinger, E. D.; MacNeal, R. H. ***Static Aeroelastic Addition to MSC/NASTRAN,*** MSC/NASTRAN Users' Conf. Proc., Paper No. 15, March, 1984.
- Rodden, W. P. ***Secondary Considerations of Static Aeroelastic Effects on High-Performance Aircraft,*** Static Aeroelasticity in Combat Aircraft, Paper No. 3, January, 1986, (AGARD Report 725).
- Rodden, William P., (ed.) ***Handbook for Aeroelastic Analysis,*** The MacNeal-Schwendler Corporation, Report No. MSR-57, November, 1987.
- Rodden, William P. ***The New MSC/NASTRAN Handbook for Aeroelastic Analysis,*** The MSC 1988 World Users Conf. Proc., Vol. II, Paper No. 63, March, 1988.
- Turner, Daniel, Dr.; Astle, Donald C. ***A Study of the Effect of Control Surface Aerodynamics on Flutter Analyses,*** Proc. of the Conf. on Finite Element Methods and Technology, Paper No. 16, March, 1981.
- Tzong, George T.J.; Sikes, Gregory D.; Dodd, Alan J. ***Large Order Modal Analysis Module in the Aeroelastic Design Optimization Program (ADOP)*** The MSC 1991 World Users' Conf. Proc., Vol. II, Paper No. 36, March, 1991.
- Visagan, G. Senthil; Elayathu, M. N. G. ***Flutter Analysis of Launch Vehicle Fin***, The First India MSC Users' Conf. Proc., December, 1992.
- Vollan, A. ***Use of MSC/NASTRAN for the Aeroelastic Analysis of the Pilatus PlC-9 Turbo Trainer,*** Proc. of the MSC/NASTRAN Eur. Users' Conf., May, 1986.
- Vollan, Arne; Alati, Loreto; Ronti, Gino. ***Unsteady Pressure Distribution of a Wing-Body Configuration: MSC/NASTRAN Results Compared with Wind Tunnel Tests,*** The MSC 1990 World Users Conf. Proc., Vol. I, Paper No. 22, March, 1990.
- Weisshaar, Terrence A.; Sadlowski, Michael. ***Panel Flutter Suppression with Active Micro-Actuators***, Int. Forum on Aeroelasticity and Structural Dynamics 1993, May, 1993.
- Winther, B. A.; Hagemeyer, D. A.; Britt, R. T.; Rodden, W. P. ***Aeroelastic Effects on the B-2 Maneuver Response***, AIAA Atmospheric Flight Mechanics Meeting, August, 1993, (AIAA-93-3664).
- Zwillenberg, Peter A. ***MSC/NASTRAN Doublet-Lattice Method Qualification and Correlation,*** The MSC 1991 World Users' Conf. Proc., Vol. I, Paper No. 9, March, 1991.

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