Flutter Analysis

A flutter analysis determines the dynamic stability of an aeroelastic system. As noted in Introduction , three methods of analysis are available: the American (K) method, a restricted but more efficient American (KE) method, and the British (PK) method. 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 dampings 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.

Features of the three flutter methods are shown in Table 2-2. 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. Brief descriptions of the K-, KE-, and PK-flutter methods follow, before the requirements of the Bulk Data entries are summarized.

Table 2-2. Flutter Analysis Methods

Feature	Method		
	K	KE	PK
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.	For Each ρ, m, V, Iterate on Each Root to Find Consistent Results.
Eigenvalue Method	Several Methods Available, Selected by User via CMETHOD in Case Control	Complex Upper* Hessenberg	Real Upper* Hessenberg

Note * No CMETHOD entry is used.

All methods 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. For example, if the user specifies two values of each, there will be eight analyses in the following order:

LOOP (CURVE)	DENS	MACH	REFREQ orVELOCITY
1	1	1	1
2	2	1	1
3	1	1	2
4	2	1	2
5	1	2	l
6	2	2	1
7	1	2	2
8	2	2	2

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. NX Nastran uses the CEAD module to extract all requested roots but only selects roots with a positive imaginary part for the flutter summary output.

alues for the parameters are listed on FLFACT Bulk Data entries. Usually, one or two of the parameters will have only a single value. Caution: 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.

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 that no damping (B) matrix is allowed and 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.

The PK-method treats the aerodynamic matrices as real frequency dependent springs and dampers. A frequency is estimated, and the eigenvalues are found. From an eigenvalue, a new frequency is found. The convergence to a consistent root is rapid. Advantages of the method are that it permits control systems analysis and that the damping values obtained at subcritical flutter conditions appear to be more representative of the physical damping. Another advantage occurs when the stability at a specified velocity is required since many fewer eigenvalue analyses are needed to find the behavior at one velocity. The input data for the PK-method also allows looping, as in the K-method. The inner loop of the user data is on velocity, with Mach number and density on the outer loops. Thus, finding the effects of variations in one or both of the two parameters in one run is possible.

The flight condition and remaining flutter control specifications are in the Bulk Data input. The AERO entry gives the basic aerodynamic data. 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. As discussed in Dynamic Aeroelastic Analysis , the K- and KE-methods of flutter analysis allow the user 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. The PK-method only supports the linear spline method. The EIGR entry selects the real eigenvalue method to obtain the vibration modes and frequencies, and, 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 (e.g., in/sec) to any units the user may desire (e.g., 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 Sample Problems.