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MILITARY SPECIFICATION

AIRPLANE STRENGTH AND RIGIDITY VIBRATION, FLUTTER, AND DIVERGENCE

This specification is approved for use by the Naval Air Systems Command, Department of the Navy, and is available for use by all Departments and Agencies of the Department of Defense.

1. SCOPE

1.1 Scope. This specification contains the general and detail design requirements and criteria in the design and construction of airplanes to:

a. Prevent flutter, divergence, and other dynamic and static aeroelastic instabilities.

b. Control structural vibrations.

c. Prevent fatigue failure of the airframe structure or structural components induced by vibrations, aeroacoustic and other oscillatory loads for the service life of the airplane.

d. Prescribe structural dynamic analyses, laboratory and ground tests, and structural dynamic flight tests required to demonstrate compliance with design requirements.

e. Apply to airplanes acquired by the Navy for all conditions of flight and surface operations for which the airplanes are required to operate.

Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: Commanding Officer, Naval Air Warfare Center Aircraft Divison Lakehurst, Code SR3, Lakehurst, NJ 08733-5100, by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

2. APPLICABLE DOCUMENTS

2.1 Government documents.

2.1.1 Specifications. The following specifications form a part of this specification to the extent specified herein. Unless otherwise specified, the issues of these documents shall be those listed in the issue of the Department of Defense Index of Specifications and Standards (DODISS) and supplement thereto, cited in the solicitation.

SPECIFICATIONS

MILITARY

MIL-A-8860	Airplane Strength and Rigidity, General Specification for.
MIL-A-8861	Airplane Strength and Rigidity Flight Loads.
MIL-A-8863	Airplane Strength and Rigidity Ground Loads for Navy Acquired Airplanes
MIL-A-8866	Airplane Strength and Rigidity Reliability Requirements, Repeated Loads, Fatigue and Damage Tolerance.

(Unless otherwise indicated, copies of federal and military specifications standards, and handbooks are available from the Standardization Document Order Desk, Building #4, Section D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.)

2.1.2 Other Government documents and publications. The following Government publications form a part of this specification to the extent specified herein. Unless otherwise specified, the issues shall be those in effect on the date of the solicitation.

PUBLICATIONS

AIR FORCE FLIGHT DYNAMICS LABORATORY (AFFDL)

TR-67-140	Design Criteria for the Prediction and Prevention of Panel Flutter;
Volume I	Criteria Presentation.
Volume II	Background Studies and Review of State of the Art.
TR-74-112	Sonic Fatigue Design Guide for Military Aircraft.

(Copies of other Government documents/publications required by contractors in connection with specific acquisition functions should be obtained from the contracting activity or as directed by the contracting activity.)

2.2 Orcer of precedence. In the event of a conflict between the text of this specification and the references cited herein (except for associated detail specifications, specification sheets or MS standards), the text of this specification shall take precedence. Nothing in this specification, however, shall supersede applicable laws and regulations unless a specific exemption has been obtained.

3. REQUIREMENTS

3.1 General requirements. Construction, materials and design of the airplane shall be such that:

a. Flutter, buzz, divergence, aeroservoelastic instability, aerothermoelastic Instability, or other related static or dynamic aeroelastic instabilities, including sustained limit amplitude instabilities, shall not occur consistent with the requirements of 3.1.1.

b. Airframe fatigue failures resulting from structural dynamic responses induced by aeroacoustic, mechanical, structural or other oscillatory loadings shall not occur consistent with the requirements of 3.1.2.

These requirements shall apply throughout the design range of altitudes, speeds, maneuvers, weights, fuel content, thermal conditions, maneuvers where losses in rigidity may occur, external and internal store configurations, and other loading conditions and configuration variables for the service life of the airplane.

3.1.1 Aeroelastic stabillty. All configurations of the airplane shall be free from any aeroelastic instability for all combinations of altitude and speed encompassed by the limit speed (V_L/M_L) versus altitude envelope enlarged at all points by the airspeed margin of safety. The airplane shall meet the following stability design requirements for both-normal and failure conditions:

a. Airspeed margin: The equivalent airspeed, We, margin of safety shall be not less than 15 percent at all points on the V_L/M_L envelope of the airplane, both at constant Mach number, M, and separately, at constant altitude, (see Figure 1).

b. Damping: The total (aerodynamic plus structural) damping coefficient, g, shall be not less than 3 percent (g=0.03) for any critical flutter mode for all altitudes and flight speeds from minimum cruising speeds up to V_L/M_L, (see Figure 2).

3.1.1.1 Aeroservoelastic stability. Interaction of the flight control system with the airplane structural modes shall be controlled to prevent any aeroservoelastic instability. The stability design requirement of 3.1.1 shall be met in all operational states of the flight control system (such as normal and failure states, reversionary modes, and augmentation system on and off (if off is a design condition)) and for the range of operating temperatures of the flight control system. In addition, for any single flight control system feedback loop, the airplane structural modes shall have the stability margins listed below at speeds up to V_L/M_L.

a. The gain margin shall be not less than 6 dB.

b. And separately, the phase margin shall be not less than 60°.

3.1.2 Vibroacoustic loads and fatigue. The design of the airplane shall be free from fatigue failures resulting from structural dynamic responses induced by vibroacoustic loadings of 3.2.2.1 for the exposure time of 3.1.2.1. The design of the airplane shall satisfy the design factors of safety and fall-safe requirements of 3.1,2.2 and 3.2.2.3, respectively, and the fatigue and damage tolerance requirements as specified in MIL-A-8866.

3.1.2.1 Exposure time. Cumulative exposure times to vibroacoustic loadings shall be consistent with the planned service life and utilization spectra as specified in MIL-A-8866, and the planned operational scenarios and mission profiles for all speeds up to V_L/M_L. In addition, time of exposure for the following specific conditions shall be:

a. Thirty seconds at maximum power when in launch position on shipboard catapult.

b. Thirty seconds behind raised jet blast deflector (JBD) when in position for next launch.

c. Fifteen minutes per 50 flight hours during ground runs at maximum power.

d. Fifteen minutes per 50 flight hours during hush house operations at maximum power.

3.1.2.2 Design factors of safety. The airplane shall meet the following design requirements:

a. Design factor of safety for aeroacoustic loads: The structure and structural components shall be designed with a design factor of safety of 1.5 on aeroacoustic pressures.

b. Scatter factor: A scatter factor of 2 on the vibroacoustic service life exposure of 3.1.2.1 shall be used in demonstration of fatigue life of airplane structure and structural components.

3.2 Detail design requirements.

3.2.1 Aeroelastic stability.

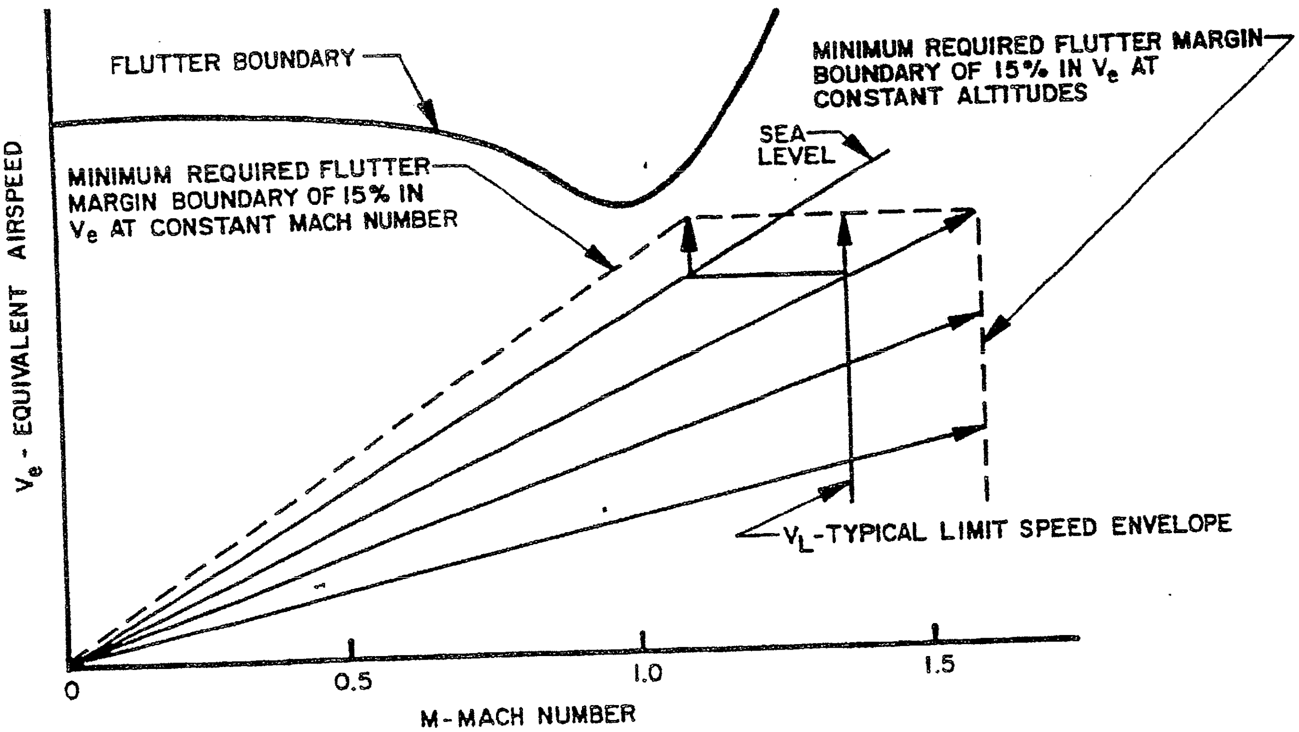

FIGURE 1. Graphical representation of minimum required flutter margin.

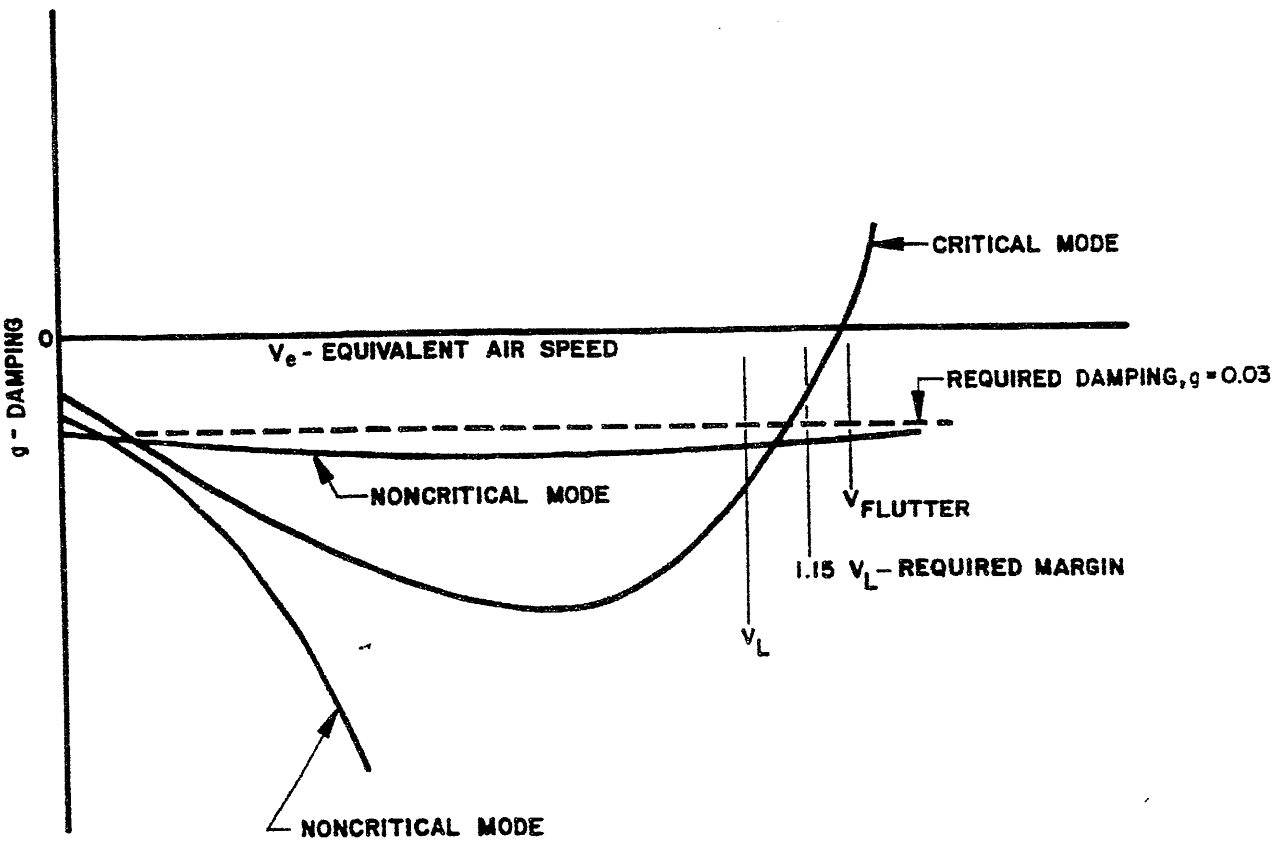

FIGURE 2. Graphical representation of required damping.

3.2.1.1 Control surfaces and tabs. Control surfaces and tabs shall be designed to contain either sufficient static and dynamic mass balance, or sufficient bending, torsional and rotational rigidity, or a combination of these means, to prevent, flutter of all critical modes under all flight conditions for normal and failure operating conditions of the actuating systems. The adequacy of mass balance or rigidity of control surfaces and tabs shall be established “ during the flutter prevention program. In addition, the following is required for tabs:

a. Trim or lagging balance tabs: A lagging balance tab is a tab installed such that its rotation is in the direction opposite that of the supporting control surface. Trim tabs or lagging balance tabs shall be not less than completely statically balanced about their hinge lines.

b. Leading balance or spring-loaded tabs: A leading balance tab is a tab installed so that its rotation is in the same direction as that of the supporting control surface. Leading balance tabs and spring-loaded tabs shall be dynamically balanced with respect to the hinge line of the supporting control surface and the tab hinge line.

3.2.1.1.1 Mass balance of control surfaces and tabs. If static mass balance or dynamic mass balance or both are used on control surfaces, tabs, and the associated components to their control systems to prevent any aeroelastic instability, the requirements as specified in 3.2.1.1.1.1 through 3.2.1.1.1.5 shall be met.

3.2.1.1.1.1 Location of balance weights. Balance weights in control surfaces and tabs shall be located so that flutter safety of both tab and control surface and main surface are assured. In addition, the following shall apply:

a. Balance weights shall be located in regions where deflections of critical mode shapes are a maximum.

b. Whenever possible, balance weights shall be distributed and each third of the span of each control surface shall be statically balanced.

c. Balance weights shall not be located externally with respect to the planes of the control surfaces.

d. Balance weights and actuating systems for control surfaces and tabs shall be designed to prevent control surface or tab rotations resulting from inertia loads acting on the balance weights and actuating systems clue to catapulting or rocket assist takeoffs.

3.2.1.1.1.2 Rigidity of balance weight attachment. The natural frequencies of the balance weights as installed shall be not less than twice the highest frequency of the flutter mode for which the balance weight is required to be effective.

3.2.1 .1.1.3 Design loads for balance weight attachment. Balance weights and the adjacent supporting structure shall be designed to the following conditions:

a. A limit inertial load factor of ± 100 g and repeated inert a load factor of ± 60 g for 500 kilocycles in a direction normal to the plane of the control surface or tab.

b. A limit inertial load factor of ± 50 g and repeated inertial load factor of ± 30 g for 500 kilocycles in the other two mutually perpendicular directions of the control surface or tab.

3.2.1.1.1.4 Provisions for rebalancing. Provisions shall be made to enable increasing or decreasing the balance to compensate for the effects of changes, repairs and painting.

3.2.1.1.1.5 Static balance tolerance. The range of allowable service static overbalance or unbalance, including manufacturing tolerances and effects of painting and repairs, of each control surface (including attached tab) and tab shall be established and included in all control surface and tab assembly drawings.

3.2.1.1.2 Environmental effects on mass properties. The design of all control surfaces and tabs shall prevent detrimental changes in mass properties (such as mass, static balance and mass moments of inertia) due to any natural environment throughout the service life of the airplane. Water absorption and water entrapment shall be prevented.

3.2.1 .1.3 Rigidity and frequency of control surfaces and tabs. If bending, torsional and rotational rigidity criteria are used for control surfaces and tabs to prevent any aeroelastic instability, the following requirements shall apply:

a. The adequacy of control surface or tab bending, torsional and rotational rigidity about the hinge line and frequency for both normal and failure operating conditions of the actuating system shall be established together with the maximum allowable changes in inertia properties (from nominal) of control surface or tab.

b. The maximum allowable inertia properties (such as weight, CG location, static unbalance about hinge line and mass moments of inertia during service conditions) shall be established and include effects of changes, structural repair and painting.

c. The bending, torsional, and rotational rigidity shall include the rigidity of all actuating elements, rigidity of the structure to which these elements are attached, and the rigidity of control surface or tab.

d. The actuators shall be located as close as practicable to the control surface or tab and to a hinge to minimize the flexibility caused by connecting elements.

3.2.1.1.4 Freeplay of control surfaces and tabs. Detail design shall assure that normal wear of components, of control surfaces and tabs, and actuating systems will not result in values of freeplay greater than those specified below throughout the service life of the airplane. Components having an adeuately established wear life may be replaced at scheduled intervals as approved by the contracting activity. However, all replacements shall be included in the wearout replacement budget established for the overall airplane.

a. For a trailing edge control surface which extends outboard of the 75 percent span station of main surface, the total freeplay shall be not greater than 0.13°.

b. For a trailing edge control surface which extends outboard of the 50 percent but inboard of the 75 percent span station of main surface, the total freeplay shall be not greater than 0.57°.

c. For a trailing edge control surface which is inboard of the 50 percent span station of main surface, the total freeplay shall be not greater than 1.15°.

d. For an all-movable control surface, the total freeplay shall be not greater than 0.034°.

e. For a tab span that is less than 35 percent of the span of supporting control surface, the total freeplay shall be not greater than 1.15°.

f. For a tab span that is equal to or greater than 35 percent of the span of supporting control surface, the total freeplay shall be not greater than 0.57°.

g. For leading edge flaps, the total freeplay shall be not greater than 0.25°.

h. For wing fold, the total freeplay shall be not greater than 0.25°.

i. For other movable components which are exposed to the airstream including, but not limited to, trailing edge flaps, spoilers, dive brakes, scoops, landing gear doors, weapon bay doors, and ventral fins (retractable, or jettisonable), the total freeplay shall be not greater than the applicable value specified above in 3.2.1.1.4 a through c.

3.2.1 .1.5 Other controls and surfaces. Airplane components which are exposed to the airstream shall be designed to contain either sufficient static and dynamic mass balance, sufficient bending, torsional, and rotational rigidity, hydraulic dampers or a combination of these means to prevent any aeroelastic instability. These components include, but are not limited to, leading edge flaps, trailing edge flaps, spoilers, dive brakes, scoops, landing gear doors, weapon bay doors, ventral fins, and blade antennas. In addition, the following shall apply:

a. When not displaced from the retracted position in flight, flaps extending outboard of the 50 percent span station of the main surface shall be rigidly locked in the retracted position.

b. If mass balanced spoilers are used, coincidence between the spoiler rotational natural frequency and low natural frequencies of the main supporting structure shall be avoided to prevent objectionable, lowly damped, gust excited oscillations.

3.2.1.1.6 Single-degree-of-freedom flutter of control surfaces. Single-degree-of-freedom flutter, such as control surface buzz, shall be prevented by providing control surface torsional and rotational rigidity, by use of hydraulic dampers, by use of aerodynamic configurations which are not susceptible to this phenomenon, or by a combination of these means.

3.2.1.1.7 Hydraulic dampers. In the event that mass balance or rigidity criteria are impracticable, two parallel hydraulic dampers may be used for flutter prevention of a control surface, tab, and any other movable component which is exposed to the airstream. In addition, the following shall apply:

a. The obtainable damping from one hydraulic damper shall be sufficient to prevent flutter.

b. The rigidities of the damper element and the supporting structure to which the elements are attached shall be sufficiently high to prevent loss of damper effectiveness by structural deformation at the flutter frequencies.

c. The freeplay of the damper shall be not greater than the applicable values specified in 3.2.1.1.4.

d. The dampers shall be effective to prevent flutter throughout the range of temperatures experienced during service.

e. Design shall be such that proper maintenance, and inspection can be readily accomplished under service conditions .

3.2.1.2 External and internal store carriage. The airplane shall be designed to prevent all aeroelastic instabilities when combinations of prescribed stores are carried on the airplane. The stability design requirements of 3.1.1 shall apply on the limit speed (V_L/M_L) envelope specified for airplanes with stores. These requirements shall apply to all carriage combinations of prescribed stores including, the following:

a. With and without wingtip stores.

b. Single and multiple carriage.

c. Standard and optional downloading.

d. Mixed stores loading.

e. Hung stores.

f. Internal stores, stoves are deployed.

g. Symmeric and asymmetric loadings.

h. Partial store expenditure, such as from external fuel tanks, rocket pods, external gun pods and dispensers.

3.2.1.2.1 External fuel tanks. Unless flutter analyses and flutter model tests indicate that the center of gravity of the fuel is riot a critical parameter which must be controlled, fuel-tight tank compartments and a fuel-sequence system shall be used in external fuel tanks to prevent adverse fuel center of gravity shifts. Where practicable, fuel-tight compartment and one-way flapper valves may be used in lieu of a fuel-sequencing system.

3.2.1.3 Fail-safe aeroelastic stability criteria. The stability design requirements of 3.1.1 shall be met after each of the adverse conditions listed below.

a. Failure, malfunction, or disconnection of any single element of the main flight control system, augmentation systems, automatic flight control systems, or tab control system.

b. Failure, malfunction, or disconnection of any single element of any flutter damper connected to a control surface or tab.

c. Detail design shall either satisfy the stability design requirements of 3.1.1 after each structural failure listed below, or provide the required static strength and fatigue life design margins such that these failures will not occur during the service life of the aircraft.

1. Failure of any single element in any hinge mechanism and its supporting Structure of any control surface or tab.

2. Failure of any single element in any actuator's mechanical attachment to structure of any control surface or tab.

3. Failure of any single element in the supporting structure of any pylon, rack, or external store.

4. Failure of any single element in the supporting structure of any large auxiliary power unit.

5. Failure of any single element in the supporting structure of any engine pod.

d. For airplanes with turbopropeller, or proprotor engines:

1. Failure of any single element of the structure supporting any engine, or independently mounted propeller shaft.

2. Any single failure of the engine structure that would reduce the yaw pitch rigidity of the propeller rotational axis.

3. Absence of propeller aeredynamic forces resulting from the feathering of any single propeller, and for airplanes with four or more engines, the feathering of the critical combination of two propellers.

4. Absence of propeller aerodynamic forces resulting from the feathering of any single propeller in combination with the failures specified in 3.2.1.3 d.1 and 3.2.1.3 d.2 above.

3.2.1.3.1 Dual failures. The airplane shall be free of any aeroelastic instabilities at all speeds up to limit speeds (V_L/M_L) for not less than 10 minutes following any combination of failures of the main flight control system augmentation system, automatic flight control system, or tab control system. These combination of failures include dual electrical system failures, or dual hydraulic system failures, or any single failure in combination with any probable hydraulic or electrical failure. After 10 minutes following any combination of failures, a safe reduced airspeed of the airplane shall be established and shall satisfy the stability design requirements of 3.1.1.

3.2.1 .3.2 Battle damage. The airplane shall be free of any aeroelastic instabilities at all speeds up to limit speeds (V_L/M_L) after battle damage due to the threats as specified in the detail specification.

3.2.1.4 Panel flutter. External, inlet, transparency and other aerodynamically loaded panels shall be designed to prevent flutter and sustained limit amplitude instabilities, and satisfy the stability design requirements of 3.1.1. In addition, the following shall apply:

a. The stiffness and damping properties of skin panels and supporting structure, such as ribs, spars, and stringers, shall be sufficiently high to prevent-panel flutter.

b. The effects of midplane stresses caused by pressure differential across the panel, temperature differential between the panel and the supporting structure, and maneuvering loads shall be included in determining the required stiffness.

The local flow aerodynamic environment (such as Mach number, dynamic pressure, and flow angularity) at the panel surface shall be used to establish panel stiffness criteria.

3.2.1.5 Transonic aeroelastic phenomena. Lifting surfaces or other airplane components shall be designed to meet the stability design requirements of 3.1.1 when exposed to shock induced oscillations or other related aeroelastic instability phenomena peculiar to the transonic flight regime.

3.2.1.6 Variable geometry airplanes. Airplanes having variable or movable geometry, such as tilt rotors, tilt wings, variable sweep, variable dibedral or pivoting stores shall be designed to prevent all aeroelastic instabilities including the effects of freeplay in pivots and joints and the interaction between lifting surfaces in close proximily.

3.2.1.7 Whirl flutter. For airplanes equipped with propeller, or proprotor engines, the propeller, powerplant, mounting systems, and pylons in combination with other components of the airplane shall be designed to prevent whirl flutter.

3.2.2 Vibroacoustic loads.

3.2.2.1 Vibroacoustic loading sources. Structural dynamic responses (vibrations) are caused by aeroaccmstic energy or mechanical energy transmitted through either air media {airborne) or solid media 9structure borne). Vibroacoustic loading environments may include those resulting from, but are not limited to, the following:

a. Propulsion system sources.

   1. Propeller noise, including blade passage loads.
   2. Jet exhaust turbulence noise.
   3. Jet exhaust turbulence noise experienced when the airplane is in launch position on shipboard catapult with JBD raised, and when behind raised JBD in position for next launch.
   4. Compressor or fan noise.
   5. Combustion noise.
   6. Nozzle instability noise.
   7. Inlet instability noise.
   8. Thrust reversers.
   9. Vectored thrust propulsion.
   10. All other sources that may be pertinent to the propulsion system.

b. Aerodynamic sources.

   1. Boundary layer pressure fluctuation.
   2. Wake noise.
   3. Cavity noise.
   4. Base pressure fluctuation.
   5. Oscillating shocks.

6. Turbulence behind open speed brakes.

7. Gun and rocket pressure blasts during firing.

8. Shed vortices from other portions of the airplane, such as engine inlet lips, wing leading edge extensions, radomes, and vortex generators.

9. Auxiliary power units (APU) noise.

10. All other noise of aerodynamic origin that may be associated with unsteady flow phenomena.

c. Mechanical sources.

1. Unbalance of rotary components.

2. Gun firing forces.

3. Secondary power sources, such as pumps, generators and compressors.

4. Fuel slosh.

5. All other mechanical phenomena.

d. Other dynamic load sources.

1. Design requirements for gusts, buffet, and store ejection shall be as specified in MIL-A-8861.

2. Design requirements for taxi, landing, catapult and arrestment shall be as specified in MIL-A-8863.

3.2.2.2 Control of environment. Techniques to minimize excessive oscillations shall be applied in the early design stages. Such techniques may include, but are not limited to, the following:

a. Relocation of oscillatory sources, such as guns, rockets, engines and APUs.

b. Isolation from the load sources with blast shields, suppressors, and isolation mounts.

c. Changing the structural stiffness locally to detune it from known frequencies of the oscillatory loads spectrum.

d. Avoidance of cavities and projections which produce local high Intensity turbulence.

e. Use of damping materials.

f. Use of baffles and absorptive materials for high velocity airflow from air conditioning systems in equipment and crew compartments.

3.2.2.3 Fail-safe structural integrity. The design of the airplane shall contain fail-safe features as specified in MIL-A-8860 so that if failures resulting from vibroacoustic loads occur, they shall not cause catastrophic failure.

3.2.2.4 Equipment shelves. The design of brackets and shelves shall prevent excessive oscillatory response of equipment clue to ampification of structural responses of the shelves and brackets.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for inspection. Unless otherwise specified in the contract or purchase order, the contractor is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified in the contract or purchase order, the contractor may use his own or any other facilities suitable for the performance of the inspection requirements specified herein, unless disapproved by the Government. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

4.1.1 Responsibility for compliance. All items must meet all requirements of section 3. The inspection set forth in this specification shall become a part of the contractor's overall inspection system or quality program. The absence of any inspection requirements in the specification shall not relieve the contractor of the responsibility of assuring that all products or supplies submitted to the Government for acceptance comply with all requirements of the contract. Sampling in quality conformance does not authorize submission of known defective material, either indicated or actual, nor does it commit the Government to acceptance of defective material.

4.1.2 Demonstration of compliance. Demonstration of compliance with each design requirement of this specification shall be verified by an integrated structural dynamic program consisting of design analyses, laboratory and ground tests, airplane ground and flight tests, and data documentation. In particular, the following shall apply:

4.1.2.1 Aeroelastic stability program. An aeroelastic stability program shall be established to insure that analyses, wind tunnel and laboratory tests, and airplane ground and flight tests (up to V_L/M_L) demonstrate that all configurations of the airplane satisfy the design requirements of 3.1.1 and 3.2.1.

4.1.2.2 Vibroacoustic loads criteria and program. A vibroacoustic loads criteria and program shall be established to insure that analyses, wind tunnel and laboratory tests, and airplane ground and flight tests (up to V_L/M_L) demonstrate that the airframe and structural components satisfy the design requirements of 3.1.2 and 3.2.2.

4.2 Structural dynamic analyses. Aeroelastic stability, vibroacoustic loading prediction, structural dynamic response and sonic fatigue analyses shall be performed as specified below.

4.2.1 Aeroelastic stability analyses.

4.2.1.1 Flutter analyses.

a. Flutter analyses shall be performed for three or more altitudes selected to include the minimum altitude at which the maximum design Mach number can be attained, the minimum altitude at which the maximum dynamic pressure can be attained, and the minimum altitude for which transonic effects begin to occur. In addition, the analyses shall be performed for any other altitudes and speeds necessary to investigate the presence of hump flutter modes which can occur inside the flight envelope.

b. Compressible aerodynamics shall be used in the high subsonic and supersonic speed ranges. Analytical or empirical corrections, as available, shall be applied for analyses in the transonic speed regime. Finite span or three-dimensional flow effects shall be included in the analyses for lifting surfaces. The effects of aerodynamic interference shall be Included for surfaces where significant flow interaction occurs.

c. The effects of transient and steady-state heating shall be included in all analyses for thermal conditions as specified in MIL-A-8860.

d. When limit-load rigidity tests show reductions in structural stiffness under load, flutter analyses shall be performed which include the lower stiffness levels at compatible flight conditions where airspeed margins of safety are minimum.

e. In cases where the results of the flutter analyses show the aeroelastic stability to be marginal or where the flutter speeds are sensitive to variations in one or more parameters, the critical parameter(s) shall be varied to cover the expected range.

f. The analyses may be based on calculated vibration modes or, if available on measured vibration modes. A sufficient number of modes shall be used to represent the important dynamic characteristics of the airplane.

4.2.1.1.1 Wing flutter analyses. Both symmetrical and antisymmetrical modes shall be investigated for various internal fuel loadings, center of gravity positions, and geometric variations. Leading edge flap(s) rotation, torsion and bending modes (including chordwise bending) shall be included in all wing flutter analyses. Analyses for wings with outboard Internal fuel tanks shall include at least the half-full forward and half-full aft center of gravity conditions in addition to the empty and full fuel conditions. Significant fuselage and empennage modes shall also be included.

4.2.1.1.1.1 External and internal stores flutter analyses. Where external and internal stores such as fuel tanks, rockets, bombs, mines, missiles, racks, and pylons are carried, the flutter analyses shall cover the range of store configurations (including single and multiple carriage, mixed store loading, standard and optional downloading, and hung stores) for which the airplane is designed or as specified in the detail specification. In addition, the following shall apply:

a. The effects of the variations of the mass and the positions of the center of gravity of variable mass items, such as fuel tanks and rocket pods, shall be included. Analyses for external fuel tanks shall include at least the half-full forward and half-full aft center of gravity conditions in addition to the empty and full fuel conditions.

b. Parametric flutter analyses shall be performed for the airplane with external and internal stores to cover the range of mass properties of store configurations on each weapon station both as a separate condition and in combination with other weapon station(s). The store parametric flutter analyses shall be performed to develop sets of plots showing iso-flutter-speed contour lines versus store configuration's weight and radius of gyration or pitch moment of inertia.

c. A full span airplane flutter analyses shall be performed to investigate the flutter characteristics of various asymmetric store loadings.

4.2.1.1.2 Empennage flutter analyses. Both symmetrical and antisymmetrical modes shall be investigated and critical parameters shall be varied to cover the expected ranges of design values. Significant fuselage modes shall also be included. For T-tail type empennages, the effects of aerodynamic interference shall be included and variations in stabilizer roll and yaw frequencies shall be made.

4.2.1.1.3 All-movable-surface flutter analyses. Both symmetrical and antisymmetrical modes shall be investigated. All-movable-surface first and second, bending, rotation, and torsion-modes shall be included in the flutter analyses. Where the axis of rotation is not in the plane of the surface, the fore-and-aft motion of the surface shall be included. The rotational frequency of the surface shall be varied over the probable range to cover both normal and emergency operations.

4.2.1.1.4 Control-surface flutter analyses. The rotational frequencies of all control surfaces shall be varied over the probable ranges to cover both normal and emergency operations. The control-surface torsional and bending degrees of freedom shall be included in the analyses.

4.2.1.1.5 Control-surface tab flutter analyses. Flutter analyses shall be performed for all tabs. The flutter analyses shall include: tab rotation. bending and torsion degrees of freedom; control surface rotation, bending and torsion degrees of freedom; and important modes of the main lifting surface, and control-system modes. The effective inertia of the control column or pedals shall be varied to cover the probable range.

4.2.1 .1.6 Trailing edge flap flutter analyses. The rotational frequencies of all trailing edge flaps shall be varied over the probable ranges to cover both normal and emergency operations. The trailing edge flap torsional and bending degrees of freedom shall be Included in the analyses.

4.2.1.1.7 Flutter analyses of other controls and surfaces exposed to the airstream. Flutter investigations shall be performed on airplane components, other than control surfaces, which are exposed to the airstream, components include flaps, dive brakes, spoilers, canard surfaces, scoops, ventral fins (fixed, retractable, or jettisonable), weapon bay doors, overwing fairings on aircraft with variable sweep wings, blade antennas, booms, and strakes.

4.2.1.1.8 Aeroservoelastic stability analyses. The dynamic characteristics of control surface actuating systems such as servo boost, fully powered servo control, and other types, shall be included in the flutter analyses. The effects of high temperatures on the dynamic characteristics of the actuating systems, including the hydraulic fluid, shall be included. Augmentation systems which may alter the dynamic response of the airplane shall also be included in the flutter analyses.

4.2.1.1.9 Panel flutter analyses. Evaluations based on existing panel flutter design criteria shall be made to determine the flutter safety of skin panels on supersonic airplanes (see AFFDL TR-67-140). In addition, the following shall apply:

a. When panels are subjected to in-plane compressive stresses due to aircraft maneuvering or aerodynamic heating, a buckled or near-buckled condition, whichever is more critical, shall be assumed unless an accurate prediction of the compressive stresses and their effects on panel flutter can be made.

b. The aerodynamic conditions used shall be the local conditions existing at the panel surface, which may be altered from the free stream by airplane attitude or surface shape.

4.2.1.1.10 Whirl mode flutter analyses. Whirl mode instability analyses shall be performed for the total and complete propeller-engine systems plus the airplane system. The analyses shall include, but not limited to, the following:

a. Airplane rigid and flexible modes, including pylon pitch and yaw modes.

b. Engine modes, including engine case modes and engine mount-isolator modes.

c. Power transmission system modes, including drive shaft modes.

d. The modes of propellers, fans, or any other blades.

e. The propeller, fan, or all other blade aerodynamic and dynamic loads, such as gyroscopic loads.

f. All accessories for all systems that are important.

4.2.1.2 Divergence analyses. Divergence analyses shall be performed for wings, stabilizers, fins, leading edge flaps, all-movable control surfaces and their actuating systems, and the leading edges of surfaces. The analyses shall be performed for the same altitudes as specified in 4.2.1.1. In addition, the following shall apply:

a. If external stores, such as wing tanks, are carried near the tip of a main surface, analyses shall be performed both with and without stores. The effects of external store fins shall be included in the analyses.

b. Analyses shall be performed for pylon-mounted engines and stores, and long slender bodies having significant lift or forward located lifting surfaces.

c. Analyses shall be performed for landing gear doors, and weapon bay doors.

d. Insofar as practicable, the sectional aerodynamic derivatives used in the analyses shall be based on experimental data.

e. Compresibility corrections shall be made where applicable.

f. The effects of transient and steady-state heating shall be included in all analyses for thermal conditions as specified in MIL-A-8850.

4.2.1.3 Fail-safe aeroelastic stability analyses. Analyses shall be performed that assume single and dual failures, and battle damage of various components of the airplane that are significant from an aeroelastic standpoint to demonstrate compliance with fail-safe aeroelastic stability criteria of 3.2.1.3. Possible losses in rigidity or changes in modal parameters resulting from these failures shall be investigated. In addition, the following shall apply:

a. For the structural elements identified in 3.2.1.3 c, analyses shall be performed to determine the static strength margins and fatigue life for the flight and ground loading conditions as specified in MIL-A-8861, MIL-A-8863 and MIL-A-8866.

b. If flutter dampers are used, then flutter analyses shall be performed to assure that the obtainable damping from one hydraulic damper is sufficient to prevent flutter.

4.2.1.4 Structural repairs. Parametric variation flutter analyses shall be performed to determine the sensitivity of the flutter speed margins of the airplane due to variation of mass properties of all control surfaces, tabs, flaps and other controls exposed to the airstream. Based on these parametric studies, the maximum structural repair mass properties allowable, without degradation in flutter speed margins, shall be established.

4.2.1.5 Changes. If there are significant differences discovered as a result of the supporting tests, including the wind tunnel model tests, design verification tests, ground vibration modal tests, rigidity tests, and flight tests, the analyses specified in 4.2.1.1 and 4.2.1.2 shall be revised.

4.2.2 Vibroacoustic loads and fatigue analyses.

4.2.2.1 <u>Vibroacoustic loading sources.</u> Vibroacoustic load environments result from sources listed in 3.2.2.1. These sources shall be evaluated to determine which of these sources are applicable to the airplane.

4.2.2.2 <u>Prediction of vibroacoustic load environments.</u>

4.2.2.2.1 <u>Aeroamustic environments.</u> Analyses shall be performed to predict the near field aeroacoustic environments of the airplane associated with engine and airplane operations on the ground, in flight, and aboard ship (including forward and aft of the JBD). The predicted environments shall include the following:

a. The characteristics of the various aeroacoustic environments, including the type of spectrum (continuous, discrete or mixed), the one-third octave band sound pressure levels, and the frequencies of discrete components of the spectrum.

b. The effects of variation in engine thrust, airspeed, dynamic pressure, and other important operating variables in the aeroacoustic environment characteristics.

c. Isobel (overall sound pressure levels) contour plots of the aeroacoustic loads, calculated for the external surface configuration of the airplane for various important operating phases and engine power settings.

d. The duration of the various aeroacoustic environments, derived from the mission profile analysis and estimated number of flights during the service life of the airplane. The derived durations shall account for all important operating phases of the airplane on the ground, aboard ship, and in flight.

4.2.2.2.1.1 <u>Internal acoustic environments.</u> The Internal acoustic environments shall be predicted. These predictions shall include the data specified in 4.2.2.2.1a, 4.2.2.2.1b and 4.2.2.2.1d above.

4.2.2.2.1.2 <u>Weapon bay internal acoustic environments.</u> The acoustic environments shall be predicted for weapon bays with and without payloads installed, and with and without open weapon bay doors. These predictions shall include the data specified in 4.2.2.2.1a, 4.2.2.2.1b and 4.2.2.2.1d above.

4.2.2.2.2 <u>Vibration and other oscillatory load environments.</u> Analyses shall be performed to predict the vibration and other oscillatory load environments of the airplane associated with engine and airplane operation; on the ground, aboard ship, and in flight. The airplane shall be divided into zones, and the vibration levels in each zone shall be predicted. In zoning the airplane, a purely geometrical zoning scheme shall be avoided and zones shall be selected based on regions of influence of the sources of vibration. The predicted environments shall include the following:

a. The characteristics of the various vibration and other oscillatory loads environments, including the type of vibration spectrum (periodic, narrow-band random, broad-band random, or transient), acceleration spectral densities, one-third octave band levels, shock spectra, the frequencies of discrete components of the spectrum, and their areas of application normally encountered by the airplane on the ground, aboard ship, and in flight, at various locations on the airframe structure.

b. The effects of variation in engine thrust, airspeed, dynamic pressure, operation of armament systems, and other important operating variables on the vibration and other oscillatory load environment characteristics.

c. The effects, where applicable, of the antivibration design implemented to control the vibration environment of the airframe structure and the crew stations.

d. The duration of the various vibration and other oscillatory load environments, derived from the mission profile analysis and estimated number of flights during the service life of the airplane. The derived durations shall account for all important operating phases of the airplane on the ground, aboard ship, and in flight.

4.2.2.3 Dynamic response analyses. Dynamic response analyses shall be performed to determine the dynamic internal loads and stresses in structural members which are induced by the dynamic environments. The dynamic environments shall include the following:

a. Gusts, buffet, and store ejection as specified in MIL-A-8861.

b. Taxi, landing, catapult, and arrestment as specified in MIL-A-8863.

4.2.2.4 Sonic fatigue analyses. Sonic fatigue analyses shall be performed to determine which structural members are susceptible to sonic fatigue damage when exposed to the aeroacoustic loading environment with the factor of safety as specified in 3.1.2.2. If the analyses indicate that sonic fatigue failures or structural defects (such as cracks, deformations, disbonds, or delamination) will occur for the above conditions, the analyses shall be repeated on redesigned structural members until a final design is evolved which will satisfy the design requirements. Sonic fatigue analyses methods are available, as a guide, in AFTDL TR-74-112.

4.2.2.4.1 Sonic fatigue life predictions. Sonic fatigue life predictions for structural members shall be based on the following parameters:

a. Dynamic response loads and the time exposure with a scatter factor of 2.

b. Material properties. Where applicable, random amplitude S-N data obtained by experiment shall be used in preference to "equivalent random amplitude" S-N curves obtained analytically by conversion of constant amplitude S-N data.

c. Notches, surface roughness, and any other stress concentrations.

d. Combined environments effects including elevated or low temperature, creep, corrosion, pressure differentials, flight and ground loads in addition to the dynamic loads.

4.2.2.5 Mass balance assembly stress and fatigue analyses. For the balance weight assemblies and the adjacent supporting structures, analyses shall be performed to determine the static strength margins and fatigue life for the applied loads as specified in 3.2.1.1.1.3.

4.2.2.6 Changes. The vibroacoustic environment predictions, dynamic response analyses, and sonic fatigue life predictions shall be revised concurrently, where applicable, with the occurrence of the following:

a. Changes in mission profile.

b. Changes in the structural design of the airplane affecting its structural dynamic response characteristics.

c. Completion of laboratory or wind tunnel tests, and ground vibration modal tests and subsequent revision of the dynamic mathematical model.

d. Completion of the aeroacoustic and vibration ground and flight tests. Where sufficient data are available, the maximum predicted environment, based on test data, shall be derived using parametric statistical methods. The data shall be tested to show a satisfactory fit to the assumed underlying distribution. The maximum predicted environment shall be defined as equal to or greater than the 95th percentile value with at least 90 percent confidence. Where there are fewer than three data samples, a minimum margin of 3.5 dB shall be applied to account for the variability of the environment.

4.3 Structural dynamic laboratory and ground tests. Structural dynamic laboratory and ground tests shall be performed as specified below.

4.3.1 Flutter model wind tunnel tests. Flutter model wind tunnel tests shall be performed early in the design stage to substantiate the airspeed margin of safety specified in 3.1.1, and to substantiate flutter analysis used to perform parameter variation investigations. Transonic models shall be used when design limit speed, M_L, is greater than 0.7 Mach number. The following shall apply:

a. These tests shall be performed with variations in dynamic pressure up to dynamic pressures which correspond to 1.32 times the airplane dynamic pressures at constant Mach number and also at constant altitude for critical Mach number regions of the design flight envelope.

b. These tests shall be performed for a sufficient range of all design variables to include a complete range of weights; required external store loadings and conditions, including down loading and hung stores; and the reduction of stiffnesses due to maneuvers and thermal environments.

c. The tests shall investigate the flutter characteristics of the wing, fuselage, empennage, and control surfaces.

d. Where the flutter speeds are sensitive to variations in one or more parameters, the critical parameter(s) shall be varied to cover the expected range.

e. If dampers are used, then tests shall be performed to assure that the obtainable damping is sufficient to prevent flutter.

4.3.1.1 Model design verification. Analysis and tests shall demonstrate that the flutter model dynamically simulates the full-scale airplane. Before the flutter models are installed in the wind tunnel, the following shall be performed to validate the models:

a. Static load-deflection tests to verify the calculated stiffness distributions.

b. Section mass properties (weight, CG location and mass moments of inertia) tests to verify the calculated values.

c. Vibration modal tests on the complete flutter model to determine modal frequencies, mode shapes and node lines, and modal damping coefficients to correlate with analytical modal parameters.

d. Vibration modal analyses, and flutter analyses of the flutter model.

4.3.1.2 Model modification. If it is determined by analysis, static tests, or vibration modal tests that significant discrepancies exist between the flutter parameters of the model and the airplane, additional tests on suitably modified models shall be performed.

4.3.2 Aeroelastic design verification tests. These tests shall be made on a flight article prior to first flight of any article. When a change is made that is likely to affect the flutter characteristics of the airplane, the tests shall be performed on a flight article incorporating the change prior to flight of any changed article. Tests of 4.3.2.1, 4.3.2.2 and 4.3.2.3 shall be repeated on the last Engineering and Manufacturing Development (E&MD) airplane.

4.3.2.1 Mass measurements of control surfaces and tabs. The total weight, static unbalance, and mass moment of inertia about the hinge line of all control surfaces, tabs. leading and trailing edge flaps shall be measured.

4.3.2.2 Freeplay measurements of control surfaces and tabs. Tests shall be performed to demonstrate that the freeplay for central surfaces, tabs, and other applicable surfaces specified in 3.2. 1.1.4 is within the limits specified in 3.2.1.1.4. The freeplay measurements shall be made for both normal and emergency operating conditions. These shall be performed prior to or during the ground vibration modal tests as follows:

a. Both clockwise and counterclockwise moments shall be applied to determine freeplay.

b. The loads used in the tests shall not cause appreciable structural deformations.

c. For tabs, the maximum has employed shall be not greater than three times the tab weight and shall be applied near the trailing edge of the tab midspan.

4.3.2.3 Rigidity tests for control surfaces and tabs. Rotational rigidity tests shall be performed on all control surfaces, tabs, and other applicable surfaces specified in 3.2.1.1.5 to determine the rigid-body rotation of the surface as a function of applied torque for both normal and emergency operating conditions. These tests may be combined with the free play tests specified in 4.3.2.2.

a. Both clockwise and counterclockwise moments shall be applied to determine rotational rigidity data.

b. Both symmetrical and antisymmetrical loading conditions shall be employed if the actuating system is such that the frequencies for the symmetrical and antisymmetrical rotational modes differ as in the case where the left-hand and right-hand elevators are connected by a torque tube.

c. Applied moments to all control surfaces and tabs shall be as large as practicable, but shall not cause structural deformations. For horizontal surfaces, the applied moment shall be at least large enough to overcome gravitational effects.

4.3.2.4 Actuator stiffness tests. Actuator stiffness tests shall be performed to determine the following:

a. Static stiffness and freeplay of the actuator(s) before and after life cycle testing.

b. Dynamic stiffness of the actuator(s) over the range of frequencies for all operating modes, including failure modes, of the system.

4.3.2.5 Balance weight attachment tests. If balance weights are used, then tests shall be performed on balance weights, attachments, and supporting structure to demonstrate that these components can withstand, without failure, the static and repeated inertia load factors specified in 3.2.1.1.1.3.

4.3.2.6 Damper tests. If dampers are used, then tests shall be performed on the damper and supporting structure to assure that components will not fall under static or repeated loads, and that the dampers will operate at high temperatures. In addition, the following shall apply:

a. Freeplay measurements shall be performed to substantiate that the freeplay is within the limits specified in 3.2. 1.1.7 c.

b. Tests shall be performed to obtain the damping characteristics as a function of frequency up to at least twice the frequency range that the damper is designed to be effective.

4.3.3 Airplane ground vibration modal tests. Airplane ground vibration modal tests shall be performed on the first E&MD airplane prior to its first flight and on the E&MD airplane to be used for aeroelastic stability flight tests (if first E&MD airplane is not used for this flight testing) prior to its first flight. These tests shall be repeated on the last E&MD airplane. The contracting activity shall be notified at least three weeks prior to commencing the ground

a. These tests shall determine modal frequencies, mode shapes and node lines, and modal damping coefficients for the assembled airplane and main airplane components. The objective of the test shall be to obtain modal data to verify, and revise if required, the analytical modal data which were used in the structural dynamic analyses (such as flutter, dynamic analyses, and flutter models).

b. Where applicable, these tests shall be used to demonstrate that resonant vibrations of the airplane structural components have been avoided when actual airplane periodic vibratory excitation loading has been applied.

c. The pitching and yawing frequencies and mode shapes of the powerplant system, including propeller, rotor, or fan, if applicable, shall be measured for use in whirl flutter calculations.

d. In addition to the conventional ground vibration modal tests on the airplane and main airplane components, vibration modal tests for control surfaces, tabs, flaps, actuating systems, and balance weights shall also be performed.

4.3.3.1 Airplane configurations. Ground vibration modal tests shall be performed for several gross weight configurations which cause significant changes in the modal parameters (frequencies and mode shapes), and flutter mechanism(s) of the airplane.

a. The variation in gross weight conditions shall include fuel loading usage, and internally carried stores.

b. For externally carried stores, if more than one type store is to be used on a given pylon, then a sufficient number of store installations shall be vibration tested to cover the probable ranges of frequencies that will be encountered. If the mass of the store is variable, such as, in a fuel tank, then the empty, half-full, and full cases shall be tested.

c. On variable geometry aircraft, tests shall be performed for appropriate positions to cover the important range of geometric variation.

4.3.3.1.1 Mass items. The airplane shall be equipped with all items having appreciable mass, such as engines, tanks, bombs, guns, external stores and similar items. Stores that may constitute a safety hazard may be inert stores or simulated with ballast weight. Fuel may be simulated by a suitable liquid.

4.3.3.2 Support of airplane. The airplane shall be supported so that the rigid body frequencies of the airplane on its support are less than one-half the frequency of the lowest elastic wing or fuselage mode to be excited. For heavy or large airplanes where unusually low structural frequencies are obtained, the method of aircraft restraint shall be discussed with the contracting activity.

4.3.3.3 Vibration test apparatus.

4.3.3.3.1 Exciting equipment. The airplane shall be vibrated by means of an exciter(s) attached at one or more places on the structure. The exciter(s) shall produce sinusoidal motion or random-motion, have stable output frequency characteristics, and have a force output relatively independent of the vibration amplitude of the structure being excited.

4.3.3.3.2 Measuring equipment. Accelerometers and associated electronic equipment shall be used to monitor and record vibration amplitude and phase. Force gages shall be installed in the drive connection between the exciter(s) and the airplane structure to monitor and record the excitation force.

4.3.3.3.2.1 Transducer locations. A sufficient number of locations shall be used to measure and define the mode shape pattern for each mode of the complete airplane. Measurement locations shall be used on all major parts of the airplane such as wings, fuselage, vertical stabilizers, horizontal stabilizers, control surfaces, engines, and if applicable on canards, leading edge flaps, trailing edge flaps, and external stores.

4.3.3.4 General vibration test procedure. Unless other procedures such as single or multiple point random excitation are preferred, the sinusoidal excitation test method is suggested as follows:

a. Frequency sweep: A vibration pickup shall be placed at a suitable location and an amplitude-frequency response curve obtained to determine the natural frequencies. The frequency increments selected shall be sufficiently small so that no important resonant peaks are overlooked. Alternate pickup and vibrator locations shall be employed as a check since node lines may have passed through the first selected vibrator and pickup locations.

b. Modal survey: At each resonant frequancy, amplitude and phase measurements shall be taken at a sufficient number of locations to define the mode of vibration. A complete airplane modal survey shall be performed for each mode.

4.3.3.4.1 Specific vibration tests.

4.3.3.4.1 Actuating systems. Vibration tests shall be performed to determine the dynamic characteristics of actuating systems, such as, servo boost, fully powered servo control, closed-loop airplane flight control systems and other related powered control systems. The tests shall be performed with the actuating system installed in tie airplane. The impedance of the control systems shall be determined both from the input and output sides of the control surfaces. In addition, tests shall be performed to determine parameters for aeroservoelastic stability analyses.

4.3.3.4.1.2 Control surfaces. For control surfaces whose rotational frequency varies with position, such as, leading edge and trailing edge flaps, the rotational frequency shall be determined for several positions.

4.3.3.4.1.3 Tabs. For tabs, the frequencies shall be corrected to include the inertia and spring effects of the vibration test apparatus. The tab relative amplitude of vibration shall be at least twice the freeplay amplitude.

4.3.3.4.1 .3.1 Spring tabs.

a. If a preloaded spring is used, tests shall be performed for several amplitudes and, also, the preload shall be completely removed.

b. The control column at the pilot’s location shall be locked, the spring tab shall be locked to the control surface, and the rotational frequency of the control surface shall then be obtained against the elastic restraint of the control system for both symmetric and antisymmetric modes.

c. The spring tab shall be locked to the control surface, the control surface shall be locked to its supporting structure, and the control column shall then be vibrated against the elastic restraint of the control system. Fundamental and higher modes of vibration shall be obtained.

d. The control cables or linkage shall be disconnected at their attachments to the control surface pivot bar or crank, the control surface shall be locked to its supporting structure and the spring tab rotational frequency shall then be obtained against the elastic restraint of the springs in the tab system.

4.3.3.4.1.4 Concentrated balance weights and attachments. The frequencies of concentrated balance weights attached to control surfaces shall be obtained in both lateral and vertical airplane directions.

4.3.3.4.1.5 Auxiliary components. The frequencies and mode shapes of speed brakes, scoops, winglets, ventral fins (fixed, retractable, or jettisonable), landing gear doors, and weapon bay doors shall be obtained.

4.3.3.4. 1.6 Airplane rigid body modes. Airplane rigid body modes listed below, when the airplane is on landing gear or on low-frequency suspensions, shall be obtained.

a. Vertical, side, and fore-and-aft translations.

b. Pitching, rolling, and yawing.

4.3.3.4.1.7 Landing gear modes. with the wheel free from the ground, the landing gear assembly modes listed below shall be obtained including their modal damping coefficients.

a. Fore-and-aft motion, symmetric and antisymmetric.

b. Lateral motion, symmetric and antisymmetric.

c. Torsional motion, symmetric and anti symmetric.

d. Any other degree of freedom which may be important for dynamic load investigations.

4.3.3.4.1.8 Skin panels. For flutter safety evaluation required by 4.2.1.1.9, the modes and frequencies of skin panels which have been determined to be flutter critical by analysis shall be obtained on the airplane.

4.3.3.4.2 Modal orthogomality. The mode shape measurements obtained shall be plotted as tests progress so that the vibration modes can be evaluated. In addition, the relative orthogonality of the modal data shall be determined as each successive mode is obtained. The generalized mass matrix obtained from an integrated triple product of the experimental orthonormalized mode shape and the theoretical mass of the system shall be determined for each aircraft weight configuration tested. All calculated off-diagonal elements of the orthogonal matrix should be not greater than 10 percent of the unit diagonal elements.

4.3.4 Laboratory vibration tests. Component surface free-free, or cantilevered, or special laboratory vibration modal tests shall be performed to verify, and revise if required, the dynamic math modeling of each component.

4.3.4.1 Component vibration modal tests. The component surface free-free vibration modal tests shall be performed to determine the modal frequencies, mode shapes and node lines, and modal damping coefficients. Test articles shall include control surfaces, tabs, leading edge flaps, trailing edge flaps, all-movable control surface, horzontal stabilizer (no elevator), vertical stabilizer (no rudder), canards, and wing torque box. These tests shall be performed on the first component fabricated early in the development phase.

4.3.4.2 Pylon vibration modal tests. A jig-mounted pylon vibration modal test shall be performed to determine the modal frequencies, mode shapes and node lines, and modal damping coefficients. The test article shall consist of the pylon, pylon-store interface structure, wing-pylon interface structure and store(s). A sufficient number of store installations shall be tested to cover the probable ranges of frequencies. If the mass property of the store is variable, such as in a fuel tank, the empty, half-full (forward and aft), 85-percent full, and full cases shall be tested, At least the yaw, pitch, and lateral bending modal properties (frequencies, mode shapes, and modal damping coefficients) shall be measured for all externally suspended store-pylon installations on the jig (fixture).

4.3.4.3 Propeller plane modes. For turbo-prop engines, the engine with propeller shall be mounted to a rigid structure. With the exciting equipment attached to the hub, propeller plane natural frequencies in pitch and yaw shall be measured. Propeller bending and torsion modes shall be measured.

4.3.4.4 Component skin panels. Component skin panel tests shall be performed to determine the effects of inplane stresses on panel modes and frequencies due to maneuvering loads or aerodynamic heating when they are of sufficient magnitude to effect panel flutter speeds. Laboratory vibration tests shall simulate the edge conditions and substructure of the panel as mounted in the airplane.

4.3.5 Rigidity tests.

4.3.5.1 Structural rigidity or influence coefficient tests. Structural rigidity or influence coefficient tests shall be performed to substantiate stiffness characteristics being employed in the flutter analyses and those used in designing flutter models. Airplane components shall be loaded statically at those loading conditions which result in reduction of structural stiffness which in turn causes flutter margins to be lowered. Airplane components shall be statically tested at various loading conditions up to and including 1.2 times limit load. At each load increment, static deflections at selected locations on the components shall be recorded. These tests shall be performed on the static test article.

4.3.5.2 Pylon structural rigidity or influence coefficient test. A jig-mounted pylon structural rigidity or influence coefficient test shall be performed to substantiate the pylon-rack stiffness characteristics being used in the flutter analyses or those used in designing flutter models.

4.3.6 Thermoplastic tests. Unless the results of analysis required by 4.2.1.1 and 4.2.1.2 indicate that a critical problem does not exist, thermoplastic tests shall be performed on airplane components. Full-scale components of the airplane shall be heated and cooled in a manner to simulate the most critical heating and cooling rates and temperatures to be encountered in flight. The components shall be vibrated in their natural modes as the heat is applied and removed so that time histories of the changes in natural frequencies are obtained. These tests shall be performed on fully instrumented components or partial components of a test article having restraint or boundary conditions as if installed on the airplane. The test articles shall not have been subjected to yield loads at any time prior to these tests.

4.3.7. Sonic fatigue component tests. Sonic fatigue component tests shall be performed on aircraft structural components to establish their prospective service lives and to substantiate the analysis of the sonic fatigue prevention proqram. These tests shall be completed during the design and analysis phase of the-sonic fatigue prevention program and as far in advance of the final design release as Possible to allow sufficient time for the redesign and retesting of components that may be found to have inadequate fatigue lives.

4.3.7.1 Structural components to be tested. Candidate structural component assemblies and subassemblies, both internal and external, for sonic fatigue tests shall be selected from each zoned area of the aircraft and shall include, but not be limited to, any of the following:

a. Structural components whose fatigue lives cannot be adequately predicted (such as structural components composed of untested or new materials, unusual design configuration, and light weight structures).

b. Structural components subjected to predicted sound pressure levels greater than 140 dB.

c. Structural components whose predicted lives are less than that required to survive sound pressure levels 3.5 dB greater than the predicted environment for the service life of the airplane with a scatter factor of two.

4.3.7.2 Test environment. Sonic fatigue tests shall be performed until the service life with a scatter factor of two is demonstrated with applied sound pressure levels 3.5 dB greater than simulated predicted environment. Other simulated environments (such as temperature and pressure differential) combined with the sonic environment shall be imposed when applicable.

4.3.7.3 Measurement and instrumentation requirements. Microphones shall be used to control and continuously monitor the acoustic environment for the test of 4.3.7.1. Strain gages, vibration transducers, or other instrumentation shall be placed on the specimen in such a manner that the dynamic response of the structure can be measured and the strain distributions can be determined. Continuous recording and monitoring of the dynamic response is necessary to detect changes which may be indicative of fatigue failures in the structure.

4.3.7.4 Fatigue-detection methods. The failure, criterion shall be based on the detection of cracks by unmagnified visual means. The fatigue detection methods shall not alter the natural response of the structure to acoustic excitation or otherwise influence the fatigue life of the test article. Changes in dynamic responses of complex structural parts could indicate out-of-sight failures. These changes include shifts in resonant frequencies and amplitude changes in vibration or stress.

4.4 Structural dynamic flight test program. The structural dynamic flight test program shall consist of:

a. Aeroelastic stability flight test.

b. Vibration ground and flight tests.

c. Aeroacoustic ground and flight tests.

4.4.1 Flight test airplane(s). The flight test airplane(s) shall be structurally, inertially and aerodynamically similar to the production airplanes and to the design presented in the structural analyses, structural dynamic analyses and drawings. Configuration, material and quality of workmanship shall be the same as for service airplanes. Significant modifications made during the development program of the airplane shall be incorporated on the test airplane(s).

4.4.1.1 Primary test airplane. The first airplane produced of each airplane model acquired shall be designated the aeroelastic stability flight test airplane. Aeroelastic stabiiity flight testing shall be performed in conjunction with expansion of Mach number, equivalent airspeed and altitude envelope.

4.4.1.2 Secondary test airplane. An additional airplane shall be designated as a backup test airplane for the aeroelastic stability flight test airplane in the event that it becomes impractical to use the primary test airplane for completion of the aeroelastic stability flight test program.

4.4.1.3 Other test airplane(s). Unless the primary or secondary test airplanes are used for the vibration and aeroacoustic flight tests, dedicated flights shall be allocated for the vibration and aeroacoustic flight tests on other test airplanes.

4.4.1.4 General Instrumentation requirements. Calibrated intrumentation shall be installed on the test airplane(s) required for the structural dynamic flight test program. A telemetry system shall be used to transmit continuous test data signals to the ground station for real-time analysis during aeroelastic stability flight tests. An onboard tape recorder shall be used for the aeroelastic stability flight tests, vibration and aeroacoustic flight tests for detailed post flight analyses.

4.4.1.4.1 Flight test parameters. Instrumentation shall be Installed on the test airplane(s) to measure the general flight parameters listed below. The data obtained from these measurements shall be used to show compliance with test requirements.

a. Airspeed and Mach number.

b. Pressure altitude.

c. Angles of attack, bank, and sideslip.

d. Normal, lateral, and longitudinal linear accelerations referenced at the center of gravity of the airplane.

e. Roll, pitch, and yaw angular rates and acceleration refenced at the center of gravity of the airplane.

f. Control surface positions.

g. Pilot's control positions.

h. Any other flight parameter pertinent to a unique structural discipline such as weapon bay door position.

4.4.1.5 Initial flight speed limits. Prior to completion of the aeroelastic stability flight test program, the initial flight speed limits for all test airplanes shall be not greater than 75 percent of the minimum critical flutter speed boundary or 75 percent of the design limit speed of the airplane, whichever is less.

4.4.2 Aeroelastic stability flight tests. Aeroelastic stability flight tests shall be performed to substantiate that all critical airplane configuration(s) are free of any aeroelastic instability, including sustained limit amplitude instabilities, throughout the prescribed design limit speed flight envelope with not less than 3 percent total (aerodynamic plus structural) damping coefficient and no predicted occurrence of an aeroelastic instability below 1.15 times design limit speed through extrapolation of flight test data. In addition, flight test data shall be used to validate analytical design data, and together with analytical, laboratory and ground test results shall demonstrate that the design requirements of this specification have been satisfied. Test configuraitons shall be as follows:

a. Practical variations of important parameters, such as weight, fuel content, and augmentation system gains, shall be investigated covering ranges of these parameters including maneuver conditions.

b. For airplanes with augmented flight controls, the tests shall be performed both with the augmentation system on and off (if system off is a design condition). The latter at test speeds for which the unaugmented airplane can be safely flown.

c. Airplanes with wingtip mounted stores shall be flight tested with and without the store.

d. For airplanes with external stores, ten of the more flutter critical airplane store configurations shall be flight tested. The critical airplane store configurations shall be based on flutter analyses and wind tunnel tests and selected from single and multiple carriage, mixed loadings, standard and optional down-loadings, hung stores, symmetric and asymmetric loadings, and partial store expenditure such as external fuel tanks, rocket launchers, external gun pods, and dispensers. Partially filled external fuel tanks shall be tested in climb, level, and dive attitudes.

4.4.2.1 Test conditions. Flight tests shall be performed with test data taken at predetermined test points, defined by Mach number and altitude, in a prescribed order of ascending criticality. The test points shall be selected at increasing Mach numbers up to design limit speed in 0.05 Mach number increments or less at constant altitude. Three or more altitudes, tested in descending order, shall be selected to include the minimum altitude at which the maximum design Mach number can be attained, the minimum altitude at which transonic effects begin to occur, and the minimum altitude at which the maximum design dynamic pressure can be attained consistent with the design limit speed envelope. The minimum altitude shall be 2,000 feet above ground level (AGL) or less, but consistent with safety of flight of the pilot and airplane. Flight tests shall also be performed at high altitudes where certain types of control surfaces are usually found to be more critical. The tests shall be performed in suitable increments for safety and the tests shall proceed after the dynamic test engineers at the ground station have determined from data analyses that it is safe to proceed.

4.4.2.2 Modal excitation system. The test airplane(s) shall be equipped with an excitation system which is capable of exciting all structural vibration modes which contribute to the various flutter critical conditions.

4.4.2.3 Transducer locations. Transducers for defining and detecting the expected modes of vibration, including frequency and damping characteristics, shall be installed during construction of the test airplanes). Accelerometers and motion sensors shall be installed and vibration response measurements made at the following locations:

a. Stabilizer tip (vertical, forward and aft, on both sides; longitudinal on one side only, but shall be located on the side having a tab if the tab is Installed on one side only).

b. Fin tip (lateral, forward and aft).

c. Control surfaces and tabs (relative rotational motion).

d. External stores (vertical, lateral, pitch, and yaw).

e. Pylon mounted engines (vertical, lateral, longitudinal, pitch, yaw, and roll).

f. Wingtips (vertical, forward and aft, on both sides longitudinal on one side only, but shall be located on the side having an aileron tab if the tab is installed on one side only).

Additional dynamic instrumentation may include four-arm-bridge strain gage circuits at the root and midspan of wings, horizontal and vertical stabilizers and on pylons on both sides of the airplane(s). These gages shall be oriented to the local elastic axes to separate bending and torsion structural deformation.

4.4.3 Vibration flight tests. Vibration flight tests shall be performed to demonstrate that the airframe structure, and structural components do not experience excessive vibration. Flight test data shall also be used to:

a. Verify, and revise if required, the predicted design Vibration environment levels.

b. Validate analytical design data, and together with analytical, laboratory and ground test data shall substantiate that fatigue failures of the airframe structure and structural components will not occur for the service life of the airplane.

4.4.3.1 Test conditions. Vibration measurements shall be made for ground and flight operating conditions. The operating conditions shall include ground engine runup to maximum thrust, taxi, takeoff, climb, level flight and maneuvers with at least five speed increments at three altitudes, approach glide, and landing. The flight altitudes and speeds shall be selected to include the minimum altitude at which the maximum design Mach number can be attained, the minimum altitude at which transonic effects begin to occur and the minimum altitude at which the maximum design dynamic pressure can be attained consistent with the design limit speed envelope. The minimum altitude shall be 2,000 feet AGL or less, but consistent with safety of flight of the airplane and pilot. The flight maneuvers shall include symmetrical pullup and pushover, wind-up turns and wind-down turns with at least five load factor increments, sideslip and split “S” at cornering speed. Vibration measurements shall also be made under the conditions listed below when they apply to the particular type of airplane being tested. The actual selected test parameters shall be consistent with the airplane mission requirements.

a. Operating afterburners and assist takeoff units.

b. Varying wing sweep angles through the permissible range.

c. During VTOL and transition conditions of V/STOL airplanes.

d. During gunfire.

e. While opening and with open weapon bays.

f. Flight near stalling speeds and at transonic speeds near Mach 1.

g. Deflecting speed brakes.

h. Lowering landing gear and operating high-lift devices, and flaps during the approach glide and landing.

i. During rapid ground accelerations or decelerations, such as catapult takeoffs, arrested landings, deploying drag chutes, and operating thrust reversers.

j. During ejection of stores or cargo.

k. Slowly applying large displacements of control surfaces, tabs, spoilers, and leading edge flaps during level flight.

l. For multiengined airplanes: Measurements shall be made for the following conditions of the vibration induced by shutting down one engine of a multiengine airplane at an altitude of not greater than 7,500 feet AGL and also within 2,000 feet of that altitude at which the maximum level flight Mach number is attained with full combat thrust at combat weight:

1. For level flight maximum speed, V_H, with all engines operating or the maximum safe speed, whichever is greater, with no specified pullout load factor.

2. For a symmetrical pullout to design limit load factor or the maximum safe load factor, whichever is less, at a speed not less than V_H with all engines operating.

4.4.3.2 Trarsducer locations. A sufficient number of transducers shall be used to define the vibration environment characteristics of the airplane. Transducer and mounting bracket or block shall not alter the response characteristics. The airplane shall be divided into zones (such as forward, center and aft fuselage, inner and outer wing, empennage, landing gear cavity, engine compartments, and nacelles and pylons) and measurements shall be made at several locations in each zone. Emphasis shall be placed on locations where high amplitude of vibration are expected to occur or where failures could be critical with respect to flight safety.

4.4.3.2.1 Empennage measurements. The empennage shall be instrumented with sufficient accelerometers, microphones, pressure transducers and strain gages to obtain data to correlate, and if required update, the predicted dynamic loadings and response. Airplane operating conditions shall be investigated to determine the dynamic environments arising from propeller or rotor wake impingement, shed vortices from other parts of the airplane, and buffet.

4.4.3.2.2 Other measurements. If applicable, vibration measurement locations shall include, but not limited to, the following:

a. External stores (vertical, lateral, pitch. and yaw).

b. Pylon mounted engines (vertical, lateral, longitudinal, pitch, yaw, and roll).

c. On structure near stores.

d. Inlets and cavities.

e. Fuselage sidewall in region of propellers.

f. Cargo compartments.

g. Wing and stabilizer tips (vertical and longitudinal), and fin tip(s) (lateral and longitudinal).

h. Control surfaces and tabs (relative rotational pickups).

i. Primary longitudinal structural members in fuselage (vertical and lateral).

j. Areas of equipment and power lines (such as avionic, electrical, mechanical, and instrument equipment, and hydraulic, pneumatic and electrical lines).

k. Gun locations: Structure and equipment located within a radius of 6 feet of the gun mountings and muzzles.

l. Balance weights: Normal and other two mutually perpendicular directions of control surfaces and tabs.

4.4.3.3 Data acquisition. The output of the transducers shall be recorded on magnetic tape for post flight analyses. The dynamic range, frequency response, and linearity, of the data acquisition system shall be compatible with the intended application of the data. The data sample length at each steady test condition shall be of sufficient duration to permit an adequate statistical analysis.

4.4.3.4 Data analyses. The vibration amplitude time histories shall be classified according to their predominant characteristics (such as periodic, random and transient) and analyzed as follows:

a. If the data are predominantly periodic, a spectral analysis (acceleration, G, versus frequency) shall be performed.

b. If the primary character of the data is random, a power spectral density analysis (G^2/Hz versus frequency) shall be performed. Sample checks for random and stationary characteristics shall be made.

c. One-third octave band analysis (Grins versus 1/3 octave band center frequency) may be performed where applicable.

d. If the vibration amplitude time history is characterized by brief duration and high peak amplitudes (such as gun fire, and landing impact), the data shall be treated as transient.

In arty case, the data analyses properties (such as effective bandwidth, sample length, averaging time, and analysis scanning rate) shall be selected (and entered into the data records) in accordance with the best practices of data analysis consistent with the data usage.

4.4.4 Aeroacoustic ground and flight test. Aeroacoustic ground and flight tests shall be performed to obtain data to verify, and revise if required, the predicted design aeroacoustic environment loads and associated structural responses. The test data shall also be used to validate analytical design data, and together with analytical and laboratory test data shall substantiate that sonic fatigue failures of the airframe structure and structural components will not occur for the service life of the airplane.

4.4.4.1 Aeroacoustic ground test. Acoustic load measurements shall be performed with the airplane in a static position on level ground in an open area where there are no large reflective surfaces within 150 feet from the airplane, other than the ground.

4.4.4.1.1 Test conditions. All engines shall be operated simultaneously at full power (with afterburners and at maximum without afterburners, if equipped with afterburners). Other engine(s) power settings and thrust reverser operation shall be used when significant high acoustic levels are expected to occur.

4.4.4.1.2 Transducer locations. A sufficient number of transducers shall be used to define the acoustic environment and associated response characteristics of the airplane as follows:

a. Acoustic measurements shall be made over all areas of the airplane which have been found to be susceptible to sonic fatigue and shall include measurements in engine inlet ducts. Measurements shall be made to determine the acoustic isobel (overall sound pressure level) contours on the airplane surface for the takeoff power condition. Near movable control surfaces, measurements shall be made with the surfaces in various positions, including those at which the acoustic load is most severe.

b. Dynamic-strain and vibration response measurements shall be made on those parts of the airplane which have been determined to be susceptible to sonic fatigue damage. The temperature of the structure experiencing significant heating shall be determined simultaneously with the acoustic measurements.

c. Internal acoustic measurements shall be made for those compartments which can be occupied by crew or passengers and for any other compartment in which the predicted overall sound pressure level equals or exceeds 130 dB.

4.4.4.1.3 Data acquisition. Acoustic, strain and vibration measurements shall be made with calibrated transducers, recorders, and associated electronic equipment. The dynamic range, frequency response, and linearity of the data acquisition system shall be compatible with the intended application or usage of the data. For acoustic measurements, the system shall have a minimum range of 30 to 10,000 Hz for frequency and a minimum range of 40 dB for magnitude resolution. Measurements shall be recorded continuously during operation of the engines.

4.4.4.1.4 Data analyses. The data analyses shall be selected in accordance with the best practices of data analyses consistent with the data usage. The acoustic data shall be reduced, analyzed and presented on appropriate plots by one-third octave band analyses of sound pressure levels in dB. The strain and accelerometer data shall be reduced, analyzed and presented on appropriate plots by power spectral density analysis.

4.4.4.2 Jet blast deflector acoustic and thermal environment tests. Tests shall be performed to demonstrate that the airplane can withstand the acoustic and thermal environment immediately forward and aft of the JBC without adverse effects on the airplane structure, structural components or engine operation.

4.4.4.2.1 Test arrangements. The airplane shall be tested forward of and aft of the JBD as follows:

a. Test airplane forward of JBD: The test airplane shall be positioned forward of JBD in three positions simulating the most critical battery positions which would exist aboard ships. These positions shall be between 58 feet and 68 feet as measured from catapult station zero to the JBD hinge line.

b. Test airplane aft of JBD: The test airplane shall be positioned aft of the JBD with a second airplane in front. The second airplane in front of the JBD shall be selected from the Navy inventory such that the airplane/JBD combination shall impart on the test airplane aft of the JBD the most critical environment. Two positions for the test airplane aft of the JBD are required and shall be as follows:

   1. The test airplane shall be centered immediately behind the JBD with the airplane centerline perpendicular to the JBD hinge line.

   2. The test airplane shall be immediately behind the JBD with the airplane centerline at a 45° angle to the JBD hinge line.

4.4.4.2.2 Test conditions. The test site shall be free of snow and water. The tests shall be performed when wind velocity does not exceed 15 knots, ambient air temperature does not exceed 80° F, and relative humidity is between 40 and 80 percent.

a. Test airplane forward of JBD: All engines of the test airplane forward of the JBD shall deliver intermediate thrust for not less than the time required to attain equilibrium structural temperature followed by maximum thrust for not less than 30 seconds.

b. Test airplane aft of JBD: The airplane in front of the JBD shall be stabilized at Intermediate thrust for 60 seconds followed by maximum thrust for not less than 30 seconds. The test airplane behind the JBD shall be operating with all engines at idle power.

4.4.4.2.3 Transducer locations. A sufficient number of transducers shall be used to define the acoustic and thermal environments of the airplane as follows.

a. The microphone sensing element shall be within 4 inches of the surface to measure pressure normal to the surface of the structure at the point of interest.

b. For imbedded microphone sensing elements which are not flush mounted to the surface of the structure, a calibrated correction factor shall be determined for adjusting the measured sound pressure level to obtain the actual oscillating pressure acting on the surface of the structure.

c. All critical external surfaces of the airplane shall be acoustically surveyed. Near movable control surfaces, measurements shall be made with the surface in various positions, including that for which the aeroacoustic load is most severe. Detailed measurements shall be made of surface areas known from design and analysis to be most susceptible to sonic fatigue damage and those areas exposed to sound pressure levels exceeding 140 dB.

d. The temperatures of structures experiencing significant heating shall be measured simultaneously with the aeroacoustic load measurements.

e. For the test airplane aft of the JBD, existing onboard engine instrumentation shall be used to record engine operation during ingestion of exhaust from the airplane forward of the JBD.

4.4.4.2.4 Data acquisition. Acoustic and thermal measurements shall be made with calibrated transducers, recorders and associated electronic equipment. The capability of the measurement and data reduction system shall have a minimum range of 30 to 10,000 Hz for frequency and a minimum range of 40 dB for magnitude resolution.

4.4.4.2.5 Data analyses. The acoustic data shall be reduced and analyzed by one-third octave band analysis and presented on appropriate plots of sound pressure levels in dB.

4.4.4.3 Aeroaccmstic flight test. Acoustic load and dynamic-strain measurements shall be made on the airplane during ground motion (including takeoff and landing) and during flight.

4.4.4.3.1 Test conditions. The operation conditions shall include ground engine-runup to maximum thrust, takeoff, climb, level flight and maneuvers with at-least five speed increments at three altitudes, and landing. The flight altitudes and speeds shall be selected to include the minimum altitude at which the maximum design Mach number can be attained, the minimum altltude at which transonic effects begin to occur, and the minimum altitude at which the maximum design dynamic pressure can be attained consistent with the design limit speed envelope. The minimum altitude shall be 2,000 feet AGL or less, but consistent with safety of flight of the airplane and pilot. The flight maneuvers shall include symmetrical pullup and pushover, wind-up turns and wind-down turns with at least five load factor increments, and accelerations and deceleration. Acoustic load measurements shall also be made under the conditions listed below when they apply to the particular type of airplane being tested. The actual parameters shall be consistent with the airplane mission requirements.

a. Operating afterburners and assist takeoff units.

b. Verying wing sweep angles throught the permissible range.

c. During gunfire.

d. While opening and with open weapon bays.

e. Deflecting speed brakes.

f. During flow turbulence such as vortex flow shedding conditions.

4.4.4.3.2 Transducer locations. A sufficient number of transducers shall be used to define the acoustic environment and associated response characteristics of the airplane as follows:

a. Acoustic measurements shall be made on airframe structure where predicted acoustic loads have been determined to be sonic fatigue significant. In addition the following areas shall be measured.

1. Aft fuselage surfaces.

2. Control surfaces.

3. Surfaces inside landing gear wells.

4. Structural surfaces near powerplant air inlet and exhaust.

5. Structures, if any, aft of flaps, spoilers, and dive brakes.

6. Surfaces inside weapon bays.

b. Dynamic-strain measurements shall be made to survey the strain responses on various areas of the airframe structure where sonic fatigue is a factor.

c. Internal acoustic measurements shall be made for those compartments which can be occupted by crew or passengers and for any other compartment in which the predicted overall sound pressure level equals or exceeds 130 dB.

4.4.4.3.3 Data acquisition. Acoustic and strain measurements shall be made with calibrated transducers, recorders and associated electronic equipment. The output of the transducers shall be recorded on magnetic tape for post flight analyses. The dynamic range, frequency response, and linearity of the data acquisition system shall be compatible with the intended application or usage of the data. However, for acoustic measurements, the system shall have a minimum range of 30 to 10,000 Hz for frequency and a minimum range of 40 dB for magnitude resolution.

4.4.4.3.4 Data analyses. The acoustic data shall be reduced, analyzed and presented on appropriate plots by one-third octave band analyses of sound pressure levels in dB. The strain data shall be reduced, analyzed and presented an appropriate plots by power spectral density analysis. In any case, the data analyses shall be selected in accordance with the best practices of data analyses consistent with the data usage.

4.4.5 Service life effects on control surfaces and tabs. During the flight test development and demonstration program, detailed freeplay measurements and rigidity tests as specified in 4.3.2.2 and 4.3.2.3, respectively, shall be performed on all control surfaces, tabs, wing folds, leading edge and trailing edge flaps of three (3) flight test airplanes to define service life effects. The tests shall be performed at 0 and at 100, 300 and 600 hours ± 25 hours of flight operations.

4.4.5.1 Maintenance instructions for control surfaces and tabs. Maintenance instructions shall be established for each control surface, tab, leading and trailing edge flap, and wingfold.

5. PACKAGING

This section is not applicable to this specification.

6. NOTES

(This section contains information of a general or explanatory nature that may be helpful, but is not mandatory.)

6.1 Intended use. The requirements of this specification are intended for use in the design, construction and substantiation of airplanes with regard to the specified aeroelastic stability, vibration control and prevention of vibration and sonic fatigue failures of structure and structural components. The requirements may be modified for specific models of airplanes by type or detail specifications, by flight test or demonstration requirements, and by other contractual documents.

6.2 Data requirements. All requirements for data shall be as specified on DD Form 1423, Contract Data Requirements List (CDRL), in the contract.

6.3 Deviations. The approval of analyses, test plans or procedures, and test reports that incorporate variations from the stated requirements does not, in itself, constitute approval of the deviation. Deviations from the contractually established requirements of this specification may be granted only by the contracting activity in written approval. Deviation requests are to be submitted to the contracting activity with sufficient engineering data to substantiate the need for and applicability of an alternate requirement.

6.4 Supersession data. This specification supersedes MIL-A-8870B(AS).

6.5 Definitions.

6.5.1 Aeroacaustic environment. The aeroacoustic environment is the pattern of sound pressure levels within specified boundaries.

6.5.2 Aeroacoustic load. The aeroacoustic load is the acoustic-noise, turbulent or separated boundary layer pressure fluctuations, or oscillating shock pressures acting on the surface of the structure.

5.5.3 Aeroelastic stability flight tests. Aeroelastic stability flight tests are the experimental means used to determine the flutter safety of an airplane. The test program is performed under carefully controlled conditions and generally in small speed increments. The dynamic response data from strategically located transducers are carefully analyzed to ensure stability before proceeding to the next higher speed.

6.5.4 Aeroelasticity. Aeroelasticity is the interaction of inertial, elastic and aerodynamic forces.

6.5.5 Aeroservoelasticity. Aeroservoelasty city is the interaction of inertial, elastic, aerodynamic forces, and the dynamics of the control system of the airplane.

6.5.6 Aerothermoelasticity. Aerothermoelasticity is the interaction of inertial, elastic, aerodynamic forces, and stresses and reduction in material mechanical properties induced by high temperature environments.

6.5.7 Asymmetric carriage. The carriage of stores arranged without symmetry. This term applies to the carriage of stores unlike in shape, physical properties, or number with reference to the plane of symmetry.

6.5.8 Augmentation system. An augmentation system is any system which increases the drive power to the actuation system to the airplane’s control surfaces.

6.5.9 Broad-band random vibration. Broad-band random vibration is random vibration having its frequency components distributed over a broad frequency band.

6.5.10 Carriage. The conveying of a store or suspension equipment by an aircraft under all flight and ground conditions, including taxi, takeoff and landing. The store or suspension equipment may be located either external or internal to the aircraft. Carriage shall include time in flight up to the point of complete separation of the store or suspension equipment from the aircraft.

6.5.11 Control surface buzz. Control surface buzz is usually evidenced by a pure rotational oscillation of a control surface or, when fixity condition are such as to restrain the motion of the surface near one end, by a torsional windup oscillation. Buzz can lead to damage or destruction of the surface either by fatigue or by inducing greater than yield loads when the amplitude is sufficiently large.

6.5.12 Damping coefficient (g). Damping coefficient, g, is expressed by the equation

$$g = (1/\pi N)\ \ln(A_i/A_j)$$

where: $N = (j - i)$
A_i = amplitude of the ith cycle
A_j = amplitude of the ith cycle

6.5.13 Divergence. Divergence is a static aeroelastic instability of a lifting surface that occurs when the structural restoring moment of the surface is exceeded by the applied aerodynamic moment.

6.5.14 Excessive vibration. Excessive vibration are those oscillatory structural accelerations which exceed the vibration environment covered by the airplane design.

6.5.15 Flutter. Flutter is a dynamic aeroelastic instability, and self-excited oscillation of an aerodynamic surface and its associated structure caused by the interaction of the aerodynamic, inertial and elastic characteristics of the components involved. At speeds below the flutter speed, oscillations will be damped. At the flutter speed, oscillations will persist with constant amplitude. At speeds above the flutter speed, oscillations will, in most cases, diverge and result in damage or destruction of the structure. Flutter is a subtopic of aeroelasticity.

6.5.16 Hung store. Any store (or stores) which does not separate from the airplane when actuated for employment or jettison.

6.5.17 Limit speed. The limit speed, V_L/M_L, as defined in MIL-A-8860.

6.5.18 Mixed load. The simultaneous carriage or loading of two or more unlike stores on a given aircraft.

6.5.19 Mode. The spatial distribution of amplitude and phase characterizing the displacement pattern of a vibrating body undergoing free undamped oscillations.

6.5.20 Multiple carriage. Carriage of more than me store on any given piece of suspension equipment, such as bombs carried on a triple ejection rack (TER), multiple ejection rack (MER) or vertical ejection rack (VER).

6.5.21 Narrow-band random vibration. Narrow-band random vibration is random vibration having frequency components only within a narrow band. It has the appearance of a sine wave whose amplitude varies in an unpredictable manner.

6.5.22 Octave. The interval between two sounds or signals having a basic frequency ratio of two.

6.5.23 Octave band analysis. An analysis made with an array of filters, the center frequencies of which are separated by one octave and the effective bandwidth of which is one octave.

6.5.24 One-third octave. The interval between two sounds or signals having a basic frequency ratio of $2^{1/3}$ (1.26).

6.5.25 <u>One-third octave band analysis.</u> An analysis made with an array of filters the center frequencies of which are separated by one-third octave and the effective bandwidth of which is one-third octave.

6.5.26 <u>Oscillation.</u> Oscillation is the variation, with time, of the magnitude of a quantity with respect to a specified reference when the magnitude is alternately greater and smaller than the reference.

6.5.27 <u>Periodic.</u> The recurrence of an oscillation at equal increments of time.

6.5.28 <u>Power spectral density.</u> Power spectral density is the limiting mean-square value (such as of acceleration, velocity, displacement, pressure, and stress) of a random variable per unit bandwidth (the limit of the mean-square value in a given rectangular bandwidth divided by the bandwidth, as the bandwidth approaches zero).

6.5.29 <u>Random vibrations.</u> Random vibration is vibration whose instantaneous magnitude is not specified for any given instant of time. The instantaneous magnitude of a random vibration is specified only by probability distribution functions giving the probable fraction of the total time that the magnitude (or some sequence of magnitudes) lies within a specified range. Random vibrations contain no periodic or quasi-periodic constituents.

6.5.30 <u>Response.</u> The response of a system is the motion (or other output quantity) resulting from an excitation (stimulus) under specified conditions.

6.5.31 <u>Single carriage.</u> Carriage of only one store on any given station or pylon.

6.5.32 <u>Sonic fatigue.</u> Sonic fatigue is the material fracture caused by the rapid reversal of stresses in the structure which in turn is caused by the fluctuating pressures associated with the aeroacoustic load produced by the flight vehicles.

6.5.33 <u>Sound pressure level.</u> The sound pressure level is 20 times the common logarithm of the ratio of the pressure of the sound to the reference pressure and is expressed in decibels, db. Four air, the reference pressure is 2 x 10-5 N/m^2.

6.5.34 <u>Spring tab.</u> A tab which is restrained directly from the control surface by a spring such that during flight the tab deflection is directly proportional to the aerodynamic forces exerted upon it.

6.5.35 <u>Stationary.</u> A statistical term that describes a random process whose spectrum and amplitude distribution do not change with time.

6.5.36 <u>Store.</u> Any device intended for internal or external carriage and mounted on aircraft suspension and release equipment, whether or not the item is Intended to be separated in flight from the aircraft. Stores include missiles, rockets, bombs, nuclear weapons, mines, torpedoes, pyrotechnic devices, detachable fuel and spray tanks, line-source disseminators, dispensers, pods (such as refueling, thrust augmentation, guns, and electronic countermeasures), targets, cargo-drop containers, and drones.

6.5.37 Suspension equipment. All airborne devices used for carriage, suspension, employment, and jettison of stores, such as racks, adapters. launchers, and pylons.

6.5.38 Symmetric carriage. An arrangement (loading) of identical stores on either side of a dividing line or plane (usually the longitudinal axis) as related to a given aircraft, suspension equipment, or weapon bay.

6.5.39 Transducer. A device capable of converting one form of energy to another. It transduces a mechanical or physical quantity or movement into an analog signal which can be transmitted to a remotely located recorder.

6.5.40 Transient vibration. A temporary vibration of a structural dynamic system, caused by an impulse.

6.5.41 The level flight maximum speed as defined in MIL-A-8860.

6.5.42 Vibration. Vibration is an oscillation of a body or a particle about a point of equilibrium. A parameter that defines the motion of a dynamic system.

6.5.43 Vibration flight tests. Vibration flight tests are the experimental means used to determine the response characteristics of the airplane to forced vibrations and impulses. Speed increments much larger than those used in aeroelastic flight tests are generally employed. The data are obtained during flight to provide information on any phenomena which may occur such as structural response due to buffeting and shed vortices, and to determine the general vibration level of the airplane.

6.5 Subject term (key word) listing.

Aeroacoustics
Aeroacoustic flight tests
Aeroelastic stability
Aeroelastic stability flight tests
Buzz
Control surfaces and tabs
Dampers
Divergence
Flutter
Freeplay
Mass balance
Oscillatory loads
Rigidity
Sonic fatigue
Vibration
Vibration flight tests

6.7 Changes from previous issue. Asterisks or vertical lines are not used in this revision to identify changes with respect to the previous issue due to the extensiveness of the changes.

Custodian:
Navy - AS

Preparing activity:
Navy - AS
(Project 1510-N056)

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INDEX - Continued

INDEX - continued

INDEX - Continued

INCH - Continued

STANDARDIZATION DOCUMENT IMPROVEMENT PROPOSAL

INSTRUCTIONS

1. The preparing activity must complete blocks 1, 2, 3, and 8. In block 1, both the document number and revision letter should be given.
2. The submitter of this form must complete blocks 4, 5, 6, and 7.
3. The preparing activity must provide a reply within 30 days from receipt of the form.

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I RECOMMEND A CHANGE:	1. DOCUMENT NUMBER MIL-A- 8870C(AS)	2. DOCUMENT DATE (YYMMDD) MARCH 25, 1993

. DOCUMENT TITLE
AIRPLANE STRENGTH AND RIGIDITY VIBRATION, FLUTTER AND DIVERGENCE

. NATURE OF CHANGE (Identify paragraph number and include proposed rewrite, if possible. Attach extra sheets as needed.)

REASON FOR RECOMMENDATION

SUBMITTER

NAME (Last, First, Middle Initial)	b. ORGANIZATION	
ADDRESS (Include Zip Code)	d. TELEPHONE (Include Area Code) (1) Commercial (2) AUTOVON (If applicable)	7. DATE SUBMITTED (YYMMDD)

PREPARING ACTIVITY

NAME COMMANDING OFFICER, NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION LAKEHURST SYSTEMS REQUIREMENTS DEPARTMENT	b. TELEPHONE (Include Area Code) (1) Commercial (908) 323-7488 (2) AUTOVON 624-7488
ADDRESS (Include Zip Code) CODE SR3 LAKEHURST, NJ 08733-5100	IF YOU DO NOT RECEIVE A REPLY WITHIN 45 DAYS, CONTACT: Defense Quality and Standardization Office 5203 Leesburg Pike, Suite 1403, Falls Church, VA 22041-3466 Telephone (703) 756-2340 AUTOVON 289-2340