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20 May 1987
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MILITARY SPECIFICATION

AIRPLANE STRENGTH AND RIGIDITY VIBRATION, FLUTTER, AND DIVERGENCE

This specification is approved for use within 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. Preclude flutter, divergence, and other dynamic and static aeroelastic instabilities.

b. Control structural vibrations.

c. Limit vibration levels in crew and passenger stations.

d. Preclude fatigue cracking initiation or delamination or any other fatigue failure of the airframe structure or structural components induced by vibrations, aeroacoustic and other oscillatory loads for the service life of the airplane.

e. Prescribe aeroelastic and dynamic analyses and structural dynamic flight tests required to assure compliance with design requirements.

1.2 Application. This specification is applicable 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: Naval Air Engineering Center, Systems Engineering and Standardization Department (Code 93), 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.

AMSC N/A FSC 1510

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1.3 Modification. These general 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.

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

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-D-8708	Demonstration Requirements for Airplanes.
MIL-A-8860	Airplane Strength and Rigidity, General Specification, For.
MIL-A-8861	Airplane Strength and Rigidity Flight Loads.
MIL-A-8866	Airplane Strength and Rigidity Reliability Requirements, Repeated Loads, and Fatigue.
MIL-A-8867	Airplane Strength and Rigidity Ground Tests.
MIL-A-8868	Airplane Strength and Rigidity Data and Reports.

2.1.2 Other Government documents (publications). The following other Government documents (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

NAVAL AIR SYSTEMS COMMAND

SD-8706	General Specification for Design Examinations, Engineering, Aircraft Weapon Systems.

(Copies of specifications and other 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 Order 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 shall be such that there will be:

a. No flutter, buzz, divergence, aeroservoelastic, aerothermoelastic or other related static or dynamic aeroelastic instabilities, including sustained limit amplitude instabilities, of the airplane weapon system consistent with the requirements of 3.1.1.

b. No airframe fatigue failures resulting from structural dynamic responses induced by aeroacoustic, mechanical, structural or other oscillatory loadings consistent with the requirements of 3.1.2.

c. No vibration levels exceeding those of 3.1.3. for crew and passenger stations.

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 store configurations, and other loading conditions and configuration variables for the service life of the airplane.

3.1.1 Aeroelastic stability. Analyses, wind tunnel and laboratory tests, and airplane ground and flight tests (up to design limit speeds) shall demonstrate that flutter, divergence and other related aeroelastic or aeroservoelastic instability boundaries occur outside the 1.15 times design limit speed envelope. The airplane shall meet the following stability design requirements for both normal and emergency conditions:

a. Margin: Fifteen percent equivalent airspeed, V_e, margin on the applicable design limit speed envelope, both at constant altitude and constant Mach number, M, (see Figure 1).

b. Damping: The damping coefficient, g, for any critical flutter mode or for any significant dynamic response mode shall be at least three percent (0.03) for all altitudes on flight speeds up to design limit speed (see Figure 2).

3.1.2 Oscillatory loads and fatigue. The design of the airplane shall be such that analyses, wind tunnel and laboratory tests, and airplane ground and flight tests, as required by the contracting activity, demonstrate freedom from fatigue failures resulting from structural dynamic responses induced by oscillatory loadings of 3.1.2.1 for the exposure time of 3.1.2.2. Structural oscillatory responses (vibrations) are caused by aeroacoustic energy or mechanical energy transmitted through either an air media (airborne) or solid media (structure borne). The design of the airplane shall also satisfy the design margins and fail-safe requirements of 3.1.2.3 and 3.1.2.4 respectively, and the requirements of MIL-A-8866.

3.1.2.1 Oscillatory loading sources. Oscillatory loading environments include, but are not limited to, those resulting from:

a. Propeller noise, including blade passage loads.

b. Jet exhaust turbulence noise, including noise experienced when in launch position on shipboard catapult with jet blast deflector (JBD) raised, and when behind raised JBD in position for next launch.

c. Compressor or fan noise.

d. Combustion noise.

e. Nozzle instability noise.

f. Inlet instability noise.

g. Thrust reversers.

h. Vectored thrust propulsion.

i. All other sources that may be pertinent to the propulsion system.

j. Boundary layer pressure fluctuation.

k. Wake noise.

l. Cavity noise.

m. Base pressure fluctuation.

n. Oscillating shocks.

o. Gun and rocket pressure blasts during firing.

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

q. Buffet during high speed and low speed maneuvers and other airplane operations.

r. Auxiliary power units (APU) noise.

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

t. Operation on ground surfaces.

u. Unbalance of rotary components.

v. Gun firing forces.

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

x. Fuel slosh.

y. External store ejection forces.

z. All other mechanical phenomena.

3.1.2.2 Exposure time. Cumulative exposure times to oscillatory loadings shall be consistent with the planned service life and utilization spectra specified in MIL-A-8866, and planned airplane operational scenarios and mission profiles. 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 JBD when in position for next launch.

c. Fifteen minutes per 50 flight hours during engine trims at maximum power.

3.1.2.3 Design margins. The airplane shall meet the following design requirements:

a. Design margins for oscillatory loads: The structure and structural components shall be designed with a design margin of 1.5 on aeroacoustic pressures and on oscillatory acceleration, G or Grms.

b. Damping: The damping coefficient, g, for any significant airframe dynamic response mode shall be at least three percent (0.03).

c. Material characteristics: A scatter factor of 2 on fatigue lives of identically manufactured structures shall be used

3.1.2.4 Fail-safe structural integrity. The design of the airplane shall contain fail-safe features as defined in 3.1.14 of MIL-A-8861. In the event unexpected fatigue failures resulting from oscillatory loadings do occur, the airplane shall still satisfy the design requirements of MIL-A-8861.

3.1.3 Crew and passenger stations vibration levels. Vibration response levels in any direction shall be controlled to preclude decreased crew proficiency, preclude crew and passenger fatigue and provide acceptable visual acuity by the crew of flight instruments, displays, and weapon sighting devices throughout the duration of the specified mission(s). The vibration response levels at crew and passenger seats, rudder pedals, heel troughs, hand terminals of control systems, work tables, and primary structural members at all crew and passenger stations shall not exceed the acceleration spectra envelopes specified in Figure 3.

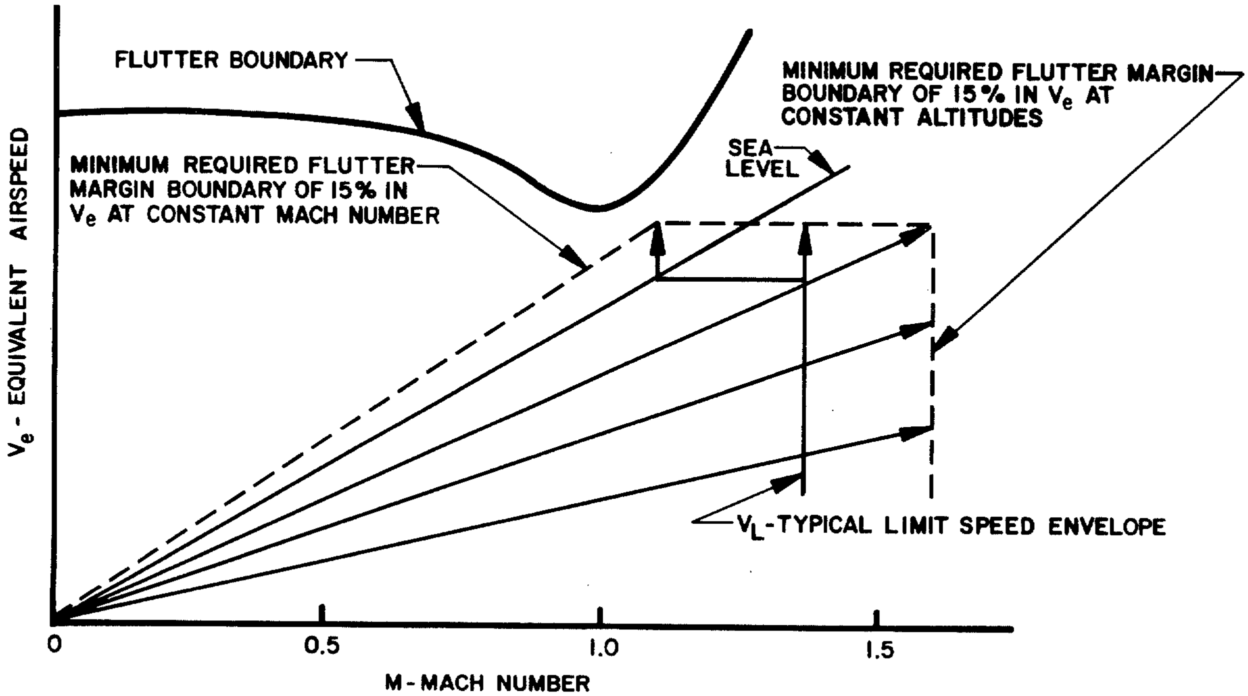

FIGURE 1. Graphical representation of minimum required flutter margin.

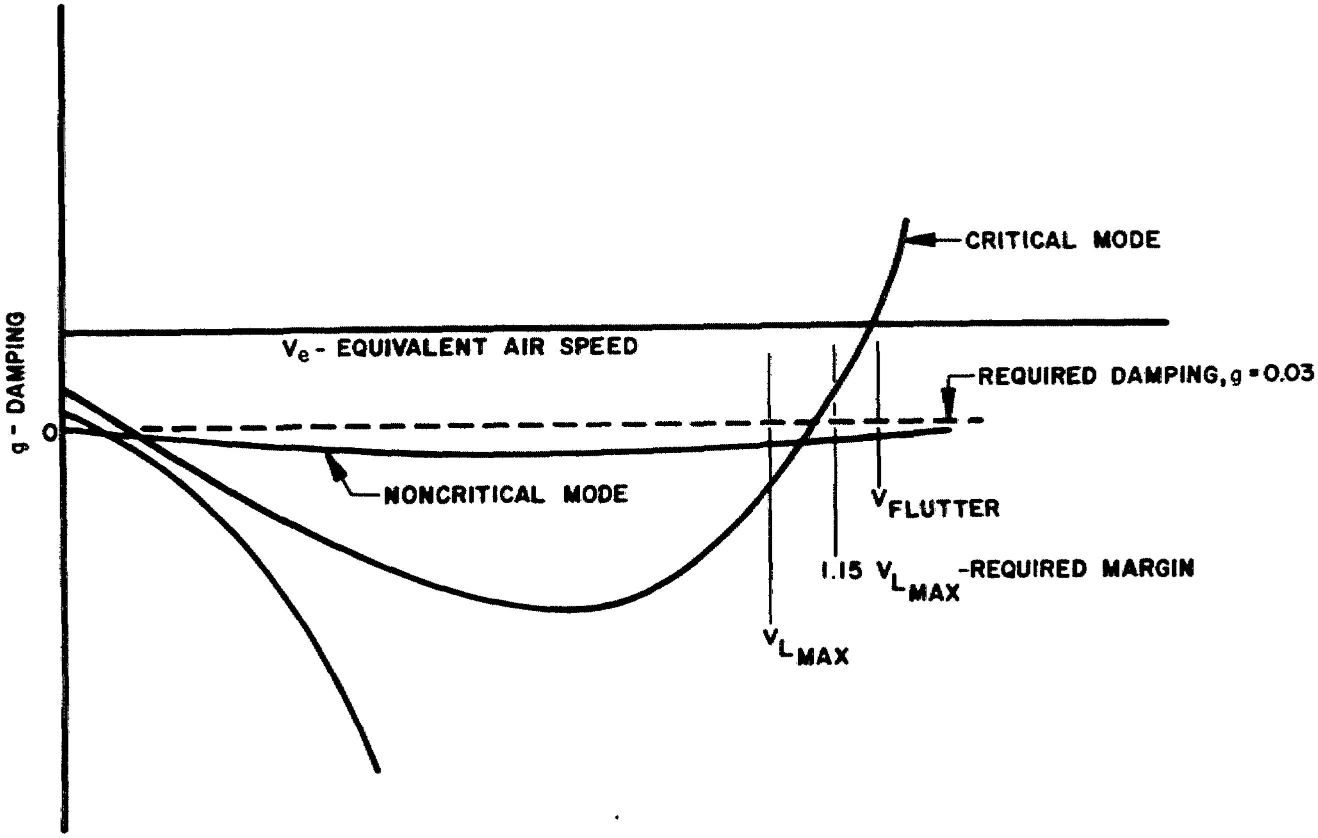

FIGURE 2. Graphical representation of required damping.

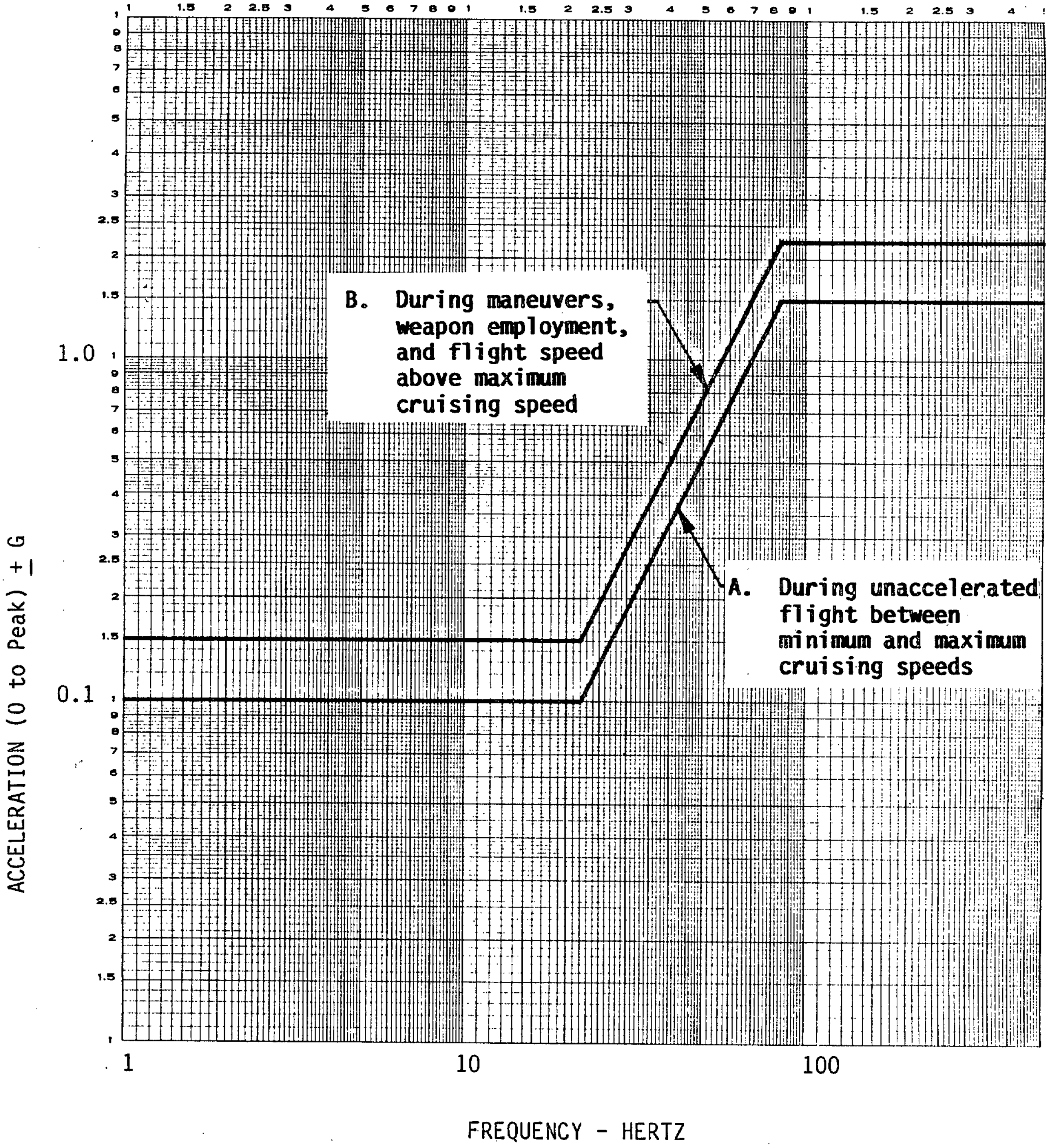

FIGURE 3. Vibration spectra envelopes at crew and passenger stations.

3.2 Detail design requirements.

3.2.1 Aeroelastic stability.

3.2.1.1 Aeroservoelastic stability. Interaction of the control system(s) with the airplane structural modes shall be controlled to preclude any aeroservoelastic instability. The equivalent airspeed margin and damping requirement of 3.1.1 shall be met with the system operating (on) and non-operating (off), and for the range of operating temperatures of the control system. In addition, for any single flight control system feedback loop, the airplane shall have the stability margins listed below at speeds up to V_L.

a. A gain margin of at least 6 dB.

b. And separately, a phase margin of at least ± 45°.

3.2.1.2 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 preclude flutter of all critical modes under all flight conditions for normal and emergency operating conditions of the actuating systems. The adequacy of mass balance or rigidity of control surfaces and tabs shall be established by flutter analyses, flutter model tests, laboratory and ground tests, and aeroelastic stability flight tests. Also, 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 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.

3.2.1.2.1 Mass balance of control surfaces and tabs. If static mass balance or dynamic mass balance or both are used on control surfaces and tabs to prevent any aeroelastic instability, the following requirements shall be met:

3.2.1.2.1.1 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 due to catapulting or rocket assist takeoffs.

3.2.1.2.1.2 Rigidity of balance weight attachment. The natural frequencies of the balance weights as installed shall be at least twice the highest frequency of the flutter mode for which the balance weight is required to be effective.

3.2.1.2.1.3 Design loads for balance weight attachment. Balance weights and the adjacent supporting structure shall be designed, as a minimum, to a static load factor of ± 100 g and repeated inertial load factor of ± 60 g for 500 kilocycles in a direction normal to the plane of the control surface or tab and ± 30 g for 500 kilocycles in the other two mutually perpendicular directions.

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

3.2.1.2.1.5 Static balance tolerance. The maximum allowable service static unbalance of each control surface (including attached tab) and tab and the manufacturing tolerances (in inch-pounds), as approved by the contracting activity, shall be established and included in all control surface and tab assembly drawings.

3.2.1.2.2 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 be applicable:

a. The adequacy of control surface or tab bending, torsional and rotational rigidity about the hinge line and frequency for both normal and emergency 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 (i.e., 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.

3.2.1.2.3 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 exceeding those specified below throughout the service life of the airplane. Components having an adequately 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 not exceed 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 not exceed 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 not exceed 1.15°.

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

e. For a tab span that is less than 35 percent of the span of supporting control surface, the total freeplay shall not exceed 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 not exceed 0.57°.

g. For wing fold, the total freeplay shall not exceed 0.25°.

h. For other movable components which are exposed to the airstream including, but not limited to, leading edge flaps, trailing edge flaps, spoilers, dive brakes, scoops and ventral fins, the total freeplay shall not exceed the applicable value specified above in 3.2.1.2.3 a through c.

3.2.1.2.4 Single-degree-of-freedom flutter of control surfaces. Single-degree-of-freedom flutter, such as control surface buzz, shall be prevented by providing adequate 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. Space, rigidity and strength shall be provided to incorporate hydraulic dampers in the event that they may by required.

3.2.1.2.5 Other controls and surfaces. Movable 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 preclude any aeroelastic instability. These components shall include, but not be limited to leading edge flaps, trailing edge flaps, spoilers, dive brakes, scoops and ventral fins. 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. 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.

3.2.1.2.6 Hydraulic dampers. In the event that mass balance or rigidity criteria are impracticable, two hydraulic dampers may be used for flutter prevention of control surfaces, tabs and other movable components which are exposed to the airstream. Flutter analyses and flutter model tests shall be performed to assure that the obtainable damping from one hydraulic damper is sufficient to prevent flutter. The rigidities of the damper element and the supporting structure to which the elements are attached shall be sufficiently high to preclude loss of damper effectiveness by structural deformation at the flutter frequencies. The freeplay of the damper shall not exceed applicable values specified in 3.2.1.2.3. The dampers shall be effective to prevent flutter throughout the range of temperatures experienced during service.

3.2.1.2.7 Environmental effects on mass properties. The design of all control surfaces and tabs shall preclude detrimental changes in physical characteristics and mass properties (i.e., mass, static balance and mass moments of inertia) due to any natural or man-made environments throughout the service life of the airplane. Water absorption and water entrapment shall be prevented.

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

3.2.1.4 External store carriage. The airplane shall be designed to preclude all aeroelastic instabilities when combinations of prescribed stores are carried on the airplane. The required 15 percent equivalent airspeed margin shall apply on the design limit speed envelope specified for airplanes with stores, both at constant altitude and constant Mach number. 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 down-loadings.

d. Hung stores.

e. Symmetric and asymmetric loadings.

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

3.2.1.5 Fail-safe stability. Detail design shall provide multiple load paths to eliminate critical single failures or, as a minimum, the design shall provide a safe life of critical elements to preclude all aeroelastic instabilities. The equivalent airspeed margin and damping requirements of 3.1.1 shall be met after each of the failures, malfunctions, or adverse conditions listed below and any other probable single failure, malfunction, or adverse condition affecting aeroelastic stability.

a. Failure, malfunction, or disconnection of any single element of the main flight-control system, augmentation systems, automatic-flight-control systems, tab-control system, or in any flutter damper connected to a control surface or tab.

b. Failure of any single element in the supporting structure of external fuel tanks, engine pods, or other external stores.

c. Failure of any single element of the structure supporting any engine, independently supported propeller shaft, or engine structure for airplanes with turbopropeller or large turbofan engines.

d. Feathering of any single propeller both as a separate condition and in combination with 3.2.1.5c. In addition, for airplanes with four or more engines, the feathering of the critical combination of two propellers.

e. Any single propeller or fan of a large turbofan engine that is rotating at the highest possible overspeed rpm.

For dual failures, the airplane shall have at least a zero-percent equivalent airspeed margin on the design limit speed envelope, both at constant altitude and constant Mach number. In addition, the damping coefficient, g, for any critical flutter mode shall be at least one percent (0.01) for all altitudes and speeds up to V_L.

3.2.1.6 Panel and chordwise mode flutter. External, inlet, transparency and other aerodynamically loaded panels shall be designed to preclude flutter and sustained limit amplitude instabilities. The stiffness and damping properties of skin panels and supporting structure, such as ribs, spars, and stringers, shall be sufficiently high to preclude panel and chordwise flutter. 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. In addition, the local flow aerodynamic environment (i.e., Mach number, dynamic pressure, flow angularity, etc.) at the panel surface shall be used to establish panel stiffness criteria.

3.2.1.7 Transonic aeroelastic phenomena. Lifting surfaces or other airplane components shall be designed to meet the equivalent airspeed margin and damping requirements of 3.1.1 when exposed to shock induced oscillations or other related aeroelastic instability phenomena peculiar to the transonic flight regime.

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

3.2.1.9 Whirl flutter. For propeller or large turbo fan equipped airplanes, the propeller, powerplant, mounting systems, and pylons in combination with other components of the airplane shall be designed to preclude whirl flutter, divergence or other related aeroelastic and dynamic instabilities.

3.2.2 Oscillatory loads and fatigue.

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

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

b. Isolation from the loads with blast shields, suppressors, isolation mounts, etc.

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

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.

3.2.2.2 Equipment shelves. The design of brackets and shelves shall prevent excessive oscillatory response of equipment due to amplification of structural responses of the shelves and brackets.

3.2.2.3 Engine antivibration mounting systems. For propeller driven airplanes, antivibration mounting systems shall be used to connect the propulsion system to the airframe. In jet powered airplanes with engines connected to the fuselage, either directly or by means of pylons, provisions shall be made for the incorporation of isolators or vibration-absorbing mounting systems so that the mounting units may be installed in the event that service experience dictates their use.

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.

4.2 General. 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, flight test and data documentation.

4.3 Demonstration of compliance.

4.3.1 Design analyses. Aeroelastic stability, oscillatory loading, and structural dynamic response and fatigue design analyses shall be performed in accordance with Appendix A and as required by SD-8706.

4.3.2 Laboratory and ground tests. Laboratory and ground tests shall be performed in accordance with MIL-A-8867 and as required by SD-8706.

4.3.3 Structural dynamic flight test program. The structural dynamic flight test program as required by MIL-D-8708 shall consist of:

a. Aeroelastic stability flight test.

b. Vibration flight test.

c. Aeroacoustic ground and flight tests.

4.3.3.1 Flight test airplane(s). The flight test airplane(s) shall be structurally, inertially and aerodynamically similar 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).

4.3.3.1.1 Primary test airplane. The first airplane produced of each airplane model acquired shall be designated the structural dynamic flight test airplane. The contractor shall perform aeroelastic stability flight testing in conjunction with expansion of Mach number, equivalent airspeed and altitude envelope.

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

4.3.3.1.3 General instrumentation requirements. The contractor shall install and calibrate the instrumentation on the test airplane(s) required for the structural dynamic flight test program. The contractor shall also be responsible for recording, telemetry, data reduction and data analyses of the required measurements. 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 vibration and aeroacoustic flight tests for detailed post flight analyses. The instrumentation, installation, calibration, data-handling equipment and methods of data reduction and analyses shall be specified and justified by the contractor and approved by the contracting activity.

4.3.3.2 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 no less than three 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 configurations are listed, but not limited to, as follows:

a. Practical variations of important parameters, such as weight, fuel content, augmentation system gains, etc., shall be investigated covering ranges of these parameters applicable to normal and emergency flight conditions including maneuvers.

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

c. For control surfaces, tabs, wingfold(s), and leading and trailing edge flaps, the tests shall be performed with the maximum allowable freeplay specified in 3.2.1.2.3 and verified by dimensional analyses and ground tests.

d. Airplane with wingtip-mounted stores shall be flight tested with and without the store.

e. For airplane with external stores, ten of the more flutter critical airplane store configurations, including the most critical, 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.

4.3.3.2.1 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 obtained, the minimum altitude at which transonic effects begin to occur, and the minimum altitude at which the maximum design dynamic pressure can be obtained consistent with the design limit speed envelope and safety of flight of the pilot and airplane. The minimum altitude need not be lower than 2,000 feet above the surface or terrain. 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.

4.3.3.2.2 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.

4.3.3.2.3 Transducer locations. Transducers suitable for clearly defining and detecting the expected modes of vibration, including frequency and damping characteristics, shall be installed during construction of the test airplane(s). As a minimum, 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 pickups shall be used to determine the motion of each control surface and tab).

d. External stores or engines (a suitable number of pickups shall be used to determine the motions of the external stores or engines).

e. 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.

4.3.3.3 Vibration flight tests. Vibration flight tests shall be performed to demonstrate that the airframe structure, structural components, equipment and crew stations do not experience excessive vibration which would contribute to structural fatigue, equipment malfunction or reduced performance of crew members. Flight test data shall also be used to:

a. Verify, and if required update, 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.

c. Demonstrate that the vibration environment levels at the crew and passenger station do not exceed the specified acceleration "G" levels.

4.3.3.3.1 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 obtained, the minimum altitude at which transonic effects begin to occur and the minimum altitude at which the maximum design dynamic pressure can be obtained consistent with the design limit speed envelope and safety of flight of the airplane and pilot. The minimum altitude need not be lower than 2,000 feet above the surface or terrain. The flight maneuvers shall include symmetrical pullup and pushdown, 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, flaps, etc., during the approach glide and landing.

i. During rapid ground accelerations or decelerations, e.g., 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 multiengine 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 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 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.

4.3.3.3.2 Transducer locations. A sufficient number of transducers shall be used to define adequately 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 (e.g., 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.

4.3.3.3.2.1 Crew and passenger stations. Vibration measurement locations shall include the following:

a. Crew and passenger seats and other locations occupied by personnel (longitudinal, lateral, and vertical).

b. Rudder pedal (longitudinal).

c. Rudder heel troughs (vertical).

d. Hand terminals of control systems (longitudinal and lateral).

e. Navigator's table and other work tables (longitudinal, lateral, and vertical).

4.3.3.3.2.2 Empennage measurements. The empennage shall be instrumented with sufficient accelerometers, microphones, pressure transducers and strain gages to obtain data to correlate, and update if required, the predicted dynamic loadings and response. All possible airplane operating conditions shall be investigated to determine critical conditions arising from, but not limited to, propeller or rotor wake impingement, shed vortices from other parts of the airplane, and buffet.

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

a. External stores and engines (a suitable number of transducers shall be used to determine the motions of external stores and engines).

b. On structure near ejectable stores.

c. Inlets and cavities.

d. Fuselage sidewall in region of propellers.

e. Cargo compartments.

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

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

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

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

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

4.3.3.3.3 Data acquisition. The output of the transducers shall be recorded on magnetic tape for post flight analyses. The dynamic range, frequency response, linearity, etc., 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.

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

a. If the data are deemed to be 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 randomness and stationarity shall be made.

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

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

In any case, the data analyses properties (i.e., effective bandwidth, sample length, averaging time, analysis scanning rate, etc.) shall be selected (and entered into the data records) in accordance with the best practices of data analysis consistent with the data usage. These properties and the criteria for their selection shall be integral to the data so that one type of vibration data may be readily converted into another (i.e., G^2/Hz into Grms).

4.3.3.4 Aeroacoustic ground and flight test. Aeroacoustic ground and flight tests shall be performed to obtain data to verify, and if required update, 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.

4.3.3.4.1 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.

4.3.3.4.1.1 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.

4.3.3.4.1.2 Transducer locations. A sufficient number of transducers shall be used to define adequately 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 contours on the airplane surface for each octave band of the excitation and for the overall sound pressure level 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.

4.3.3.4.1.3 Data acquisition. Acoustic, strain and vibration measurements shall be made with calibrated transducers, recorders, and associated electronic equipment. The dynamic range, frequency response, linearity, etc., 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.

4.3.3.4.1.4 Data analyses. The data analyses shall be selected in accordance with the best practices of data analyses consistent with the data usage. As a minimum, the acoustic data shall be reduced, analyzed and presented on appropriate plots by one-third octave band analyses of sound pressure levels in dB (ref: 2×10^{-5} N/M^2) versus frequency. The strain and accelerometer data shall be reduced, analyzed and presented on appropriate plots by power spectral density analysis.

4.3.3.4.2 Catapult aeroacoustic and thermal ground tests. Catapult aeroacoustic and thermal tests shall be performed to demonstrate that the airplane can withstand the catapult environment immediately forward and aft of the JBD without adverse effects on the airplane structure, structural components or engine operation.

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

a. Airplane forward of JBD: The 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. Airplane aft of JBD: The airplane shall be positioned aft of the JBD at two critical locations as determined by analysis and approved by the contracting activity such that the airplane can be launched within 60 seconds after the airplane forward of the JBD is launched. The airplane on the catapult shall be selected from the Navy inventory such that the airplane/JBD combination shall impart on the airplane aft of the JBD the most critical environment.

4.3.3.4.2.2 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. All engines of the 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 at least 30 seconds. The airplane behind the JBD shall be operating with all engines at idle power.

4.3.3.4.2.3 Transducer locations. A sufficient number of transducers shall be used to define adequately the acoustic and thermal environments of the airplane. 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. For 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. 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. The temperatures of structures experiencing significant heatings shall be measured simultaneously with the aeroacoustic load measurements.

4.3.3.4.2.4 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.

4.3.3.4.2.5 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 (ref: 2×10^{-5} N/M^2) versus frequency.

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

4.3.3.4.3.1 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 obtained, the minimum altitude at which transonic effects begin to occur, and the minimum altitude at which the maximum design dynamic pressure can be obtained consistent with the design limit speed envelope and safety of flight of the airplane and pilot. The minimum altitude need not be lower than 2,000 feet above the surface or terrain. The flight maneuvers shall include symmetrical pullup and pushdown, 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. Varying wing sweep angles through the permissible range.

c. During gunfire.

d. While opening and with open weapon bays.

e. Deflecting speed brakes.

4.3.3.4.3.2 Transducer locations. A sufficient number of transducers shall be used to define adequately 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.

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.

4.3.3.4.3.3 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, linearity, etc., 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.

4.3.3.4.3.4 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 (ref: 2×10^{-5} N/M^2) versus frequency. The strain data shall be reduced, analyzed and presented on 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.

4.3.4 Service life effects on control surfaces and tabs. During the flight test development and demonstration program, detailed freeplay measurements and rigidity tests shall be performed on three (3) FSD airplanes to define service life effects on all control surfaces, tabs, wingfold(s), leading edge and trailing edge flaps. The tests shall be performed in accordance with MIL-A-8867 at 0 and at 100, 300 and 600 hours ± 25 hours of flight operations. The contractor shall submit to the contracting activity a proposed plan and rough order of magnitute (ROM) cost to perform these tests on three production airplanes to define service life effects beyond 600 flight hours.

4.3.5 Contract data requirements. Required deliverable data shall be in accordance with MIL-A-8868, as required by SD-8706 and MIL-D-8708, and as specified on DD Form 1423 (CDRL).

5. PACKAGING

This section is not applicable to this specification.

6. NOTES

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.

6.2 Ordering data.

This paragraph is not applicable to this specification.

6.3 Definitions.

6.3.1 Aeroelasticity. Aeroelasticity is the study of those physical phenomena which involve significant mutual interaction among inertial, elastic and aerodynamic forces. In the context, throughout the specification the term aeroelasticity is reserved to denote the interaction of all significant aspects of fluid and solid mechanics, and any significant additional interactions.

6.3.2 Aeroservoelasticity. Aeroservoelasticity is the study of those physical phenomena which involve significant mutual interaction among inertial elastic, and aerodynamic forces and the dynamics of the control system of the airplane.

6.3.3 Aerothermoelasticity. Aerothermoelasticity is the study of those physical phenomena which involve significant mutual interaction among inertial, elastic and aerodynamic forces and stresses and reduction in material mechanical properties induced by high temperature environments.

6.3.4 Aeroelastic flight tests. Aeroelastic 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.

6.3.5 Aeroacoustic environment. The aeroacoustic environment is the acoustic-noise field pattern within specified boundaries.

6.3.6 Aeroacoustic load. The aeroacoustic load is the acoustic-noise or psuedonoise oscillating pressures acting on the surface of the structure.

6.3.7 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.

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

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

6.3.10 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.

6.3.11 Control surface buzz. Control surface buzz is a single-degree-of-freedom flutter that 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. It is caused by aerodynamic phase lags associated with boundary layer and shock wave effects and interactions which result in loss of aerodynamic damping. Buzz is usually limited in amplitude at any given speed and altitude for a given lift coefficient. The amplitude of buzz usually increases with an increase in lift coefficient. 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.

6.3.12 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 i^{th} cycle
A_j = amplitude of the j^{th} cycle

6.3.13 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.

6.3.14 Excessive vibration. Excessive vibration are those structural oscillatory accelerations, displacements, or stresses in structural or other components, which result in the component not being fully functional.

6.3.15 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.

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

6.3.17 Limit speed (V_L). The design limit speed, V_L, is defined in MIL-A-8860.

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

6.3.19 Mode. The spatial distribution of amplitude and phase characterizing the displacement pattern of a vibrating body undergoing free undamped oscillations. A normal mode of vibration is a mode describing the relative amplitudes of various structural points at a natural frequency of the system.

6.3.20 Multiple carriage. Carriage of more than one 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).

6.3.21 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.

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

6.3.23 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.

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

6.3.25 One-third octave band analysis. 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.

6.3.26 Oscillation. 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.

6.3.27 Periodic. The recurrence of an oscillation at equal increments of the independent variable.

6.3.28 Power spectral density. Power spectral density is the limiting mean-square value (e.g., of acceleration, velocity, displacement, pressure, stress etc.) of a random variable per unit bandwidth (i.e., the limit of the mean-square value in a given rectangular bandwidth divided by the bandwidth, as the bandwidth approaches zero).

6.3.29 Random vibrations. 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.

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

6.3.31 Single carriage. Carriage of only one store or any given station or pylon.

6.3.32 Sonic fatigue. 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 acoustic noise produced by the flight vehicles.

6.3.33 Sound pressure level. 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. For air, the reference pressure is 2×10^{-5} N/M^2.

6.3.34 Stationary. A statistical term that describes a random process whose spectrum and amplitude distribution do not change with time.

6.3.35 Store. 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 (refueling, thrust augmentation, guns, electronic countermeasures, etc.), targets, cargo-drop containers, and drones.

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

6.3.37 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.

6.3.38 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.

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

6.3.40 Vibration. Vibration is an oscillation wherein the quantity is a parameter that defines the motion of a structural dynamic system.

6.3.41 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, shed vortices, etc., and to determine the general vibration level of the airplane.

6.4 Supersession data. See supersession data in section 6 of MIL-A-8860. This specification supersedes MIL-A-8870(ASG). It also supersedes, in part, MIL-A-008870A(USAF), although MIL-A-008870A(USAF) will remain in effect until cancelled by the Air Force.

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-fatique
Vibration
Vibration flight tests

6.6 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.

Preparing activity:
Navy - AS

(Project 1510-N029)

APPENDIX A

STRUCTURAL DYNAMIC DESIGN ANALYSES

10. SCOPE

10.1 Scope. This appendix details the structural dynamic analyses required to insure that the airplane will meet the design requirements. This appendix is a mandatory part of the specification. The information contained herein is intended for compliance.

20. APPLICABLE DOCUMENTS

20.1 Government documents.

20.1.1 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-8866	Airplane Strength and Rigidity Reliability Requirements, Repeated Loads, and Fatigue.

20.1.2 Other Government documents (publications). The following other Government documents (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 FIGHT DYNAMICS LABORATORY (AFFDL)

TR-67-140 Design Criteria for the Prediction and Prevention of Panel Flutter;

Volume I - Criteria Presention.
Volume II - Background Studies and Review of State of the Art.

TR-74-112 Sonic Fatigue Design Guide for Military Aircraft.

(Copies of specifications and 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.)

30. STRUCTURAL DYNAMIC ANALYSES

30.1 Aeroelastic analyses.

30.1.1 Flutter analyses. Flutter analyses shall be performed for the minimum altitude at which the maximum design Mach number can be obtained, the minimum altitude at which the maximum dynamic pressure can be obtained, and the minimum altitude for which transonic effects can be obtained. In addition, the analyses shall be performed for any other altitudes deemed necessary by the contractor or the contracting activity. 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. The effects of transient and steady-state heating shall be included in all analyses for thermal conditions specified in MIL-A-8860. When limit-load rigidity tests show reductions in structural stiffness under load, flutter analyses shall be performed which shall include the lower stiffness levels at compatible flight conditions where flutter margins are minimum. In cases where the results of the flutter analyses show the flutter 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. 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. The following analyses shall be performed.

30.1.1.1 Wing 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. Significant fuselage and empennage modes shall also be included. 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 and 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. In addition, a full span airplane flutter analyses shall be performed to investigate the flutter characteristics of various asymmetric store loadings selected by the contractor and contracting activity.

30.1.1.2 Empennage 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.

30.1.1.3 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 ranges to cover both normal and emergency operations.

30.1.1.4 Control-surface flutter analyses. The rotational frequencies of all control surfaces shall be varied in the flutter analyses to cover the probable ranges of operation. The control-surface torsional and bending degrees of freedom shall be included in the analyses.

30.1.1.5 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; important modes of the degrees of freedom; and important modes of the main lifting surface, and control-system modes. The effective inertia of the contol column or pedals shall be varied to cover the probable range.

30.1.1.6 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. Items 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, booms, and strakes.

30.1.1.7 Aeroservoelastic 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.

30.1.1.8 Chordwise mode flutter. Evaluations based on existing experimental and theoretical data shall be made to determine that the required flutter margin of safety exists for those structural sections and surfaces on supersonic aircraft which are deemed to be most susceptible to chordwise mode flutter.

30.1.1.9 Panel flutter. Evaluations based on existing panel flutter design criteria shall be made to determine the flutter safety of those skin panels on supersonic airplanes deemed most susceptible to flutter (see AFFDL TR-67-140). 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. 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.

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

a. Airframe and airplane 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.

30.1.2 Divergence analyses. Divergence analyses shall be performed for all wings, stabilizers, fins and leading edge flaps. 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. Divergence analyses shall also be performed for pylon-mounted engines and stores, long slender bodies having significant lift or forward located lifting surfaces, all-movable control surfaces and their actuating systems, and the leading edges of surfaces. Insofar as practicable, the sectional aerodynamic derivatives used in the analyses shall be based on experimental data. Compressibility corrections shall be made where applicable. The effects of transient and steady-state heating shall be included in all analyses for thermal conditions specified in MIL-A-8860. The analyses shall be performed for the same altitudes specified in 30.1.1.

30.1.3 Fail safe. Analyses shall be performed that assume failures of various components of the airplane that are significant from an aeroelastic standpoint. Possible losses in rigidity or changes in modal parameters resulting from these failures shall be investigated. At least the following failures, malfunctions, or adverse conditions shall be analyzed:

a. Failure, malfunction, or disconnection of any single element of the main flight control system, augmentation systems, automatic flight control system, tab control system, or in any flutter damper connected to a control surface or tab.

b. Failure of any single element in the supporting structure of external fuel tanks, engine pods or other external stores.

c. Failure of any single element of the structure supporting any engine, independently supported propeller shaft, or engine structure for airplane with turbopropeller or large turbofan engines.

d. Absence of propeller aerodynamic forces resulting from feathering of any single propeller both as a separate condition and in combination with 30.1.3c. In addition, for aircraft with four or more engines, the feathering of the critical combination of two propellers.

e. Failure, of any single propeller or fan of a large turbofan engine that is rotating at the highest possible overspeed rpm.

30.1.4 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.

30.1.5 Changes. When changes occur in the structural design of the airplane, in the configuration of the airplane (e.g., addition of stores), in the mission of the airplane (extension of flight envelope), or any other changes affecting the flutter characteristics of the airplane, the analyses specified in 30.1.1 and 30.1.2 shall be updated. In addition, if there are significant differences discovered as a result of the supporting tests, including the wind tunnel model tests, compliance tests, ground vibration modal tests, rigidity tests, flight tests, etc., the appropriate analyses shall be corrected.

30.2 Dynamic loads and fatigue analyses.

30.2.1 Oscillatory loading sources. Structural dynamic responses (oscillations) are caused by aeroacoustic energy or mechanical energy transmitted through either an air media (airborne) or solid media (structureborne). Oscillatory loading environments result from sources listed in 3.1.2.1.

30.2.2 Prediction of dynamic load environments.

30.2.2.1 Aeroacoustic environments. 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 and one-third octave bands) 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.

30.2.2.2 Vibration and other oscillatory load environments. Analyses shall be performed to predict the vibration and other oscillatory load environments of the airplane associated with engine and airplane operations on the ground, aboard ship, and in flight, including external store ejection. 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. A separate set of vibration spectra shall be determined for each zone and each portion of airplane ground and flight operations, including maneuvers. For each set of spectra, a vibration spectrum shall be defined along each of the three mutually perpendicular axes. 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, narrowband random, broadband 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 and at the crew stations.

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.

30.2.3 Dynamic response analyses. Dynamic response analyses shall be performed to determine the dynamic internal loads and stresses, which are induced by the dynamic environments, in airframe structural members and localized attachment areas where equipment are supported by airframe structure.

30.2.4 Dynamic-fatigue analyses. Dynamic-fatigue analyses shall be performed to determine which structural members are susceptible to dynamic-fatigue damage. Sonic-fatigue analyses methods are available, as a guide, in AFFDL TR-74-112. The dynamic-fatigue analyses shall be performed for the structural members exposed to the dynamic loading environment with the required 1.5 design margin for a time period of four times the service life of the airplane (airplane service life is specified in MIL-A-8866). If the analyses indicate that dynamic-fatigue failures or structural defects (cracks, deformations, disbonds, delaminations, etc.) 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.

30.2.4.1 Dynamic-fatigue life predictions. Dynamic-fatigue life predictions for structural members shall be based on the following parameters:

a. Dynamic response loads and the time exposure to those loads.

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.

30.2.5 Changes. The dynamic environment predictions, dynamic response analyses, and dynamic-fatigue life predictions shall be updated concurrently, where applicable, with the occurrence of the following:

a. Changes in the configuration of the airplane affecting the dynamic environment; i.e., addition of stores, change in engines, etc.

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 value at the ninety-fifth 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.

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STANDARDIZATION DOCUMENT IMPROVEMENT PROPOSAL

(See Instructions – Reverse Side)

1. DOCUMENT NUMBER	2. DOCUMENT TITLE
MIL-A-8870B(AS)	Airplane Strength and Rigidity Vibration, Flutter, and Divergence

3a. NAME OF SUBMITTING ORGANIZATION	4. TYPE OF ORGANIZATION *(Mark one)*
	☐ VENDOR ☐ USER ☐ MANUFACTURER ☐ OTHER *(Specify)*: ______
b. ADDRESS *(Street, City, State, ZIP Code)*	

5. PROBLEM AREAS

a. Paragraph Number and Wording:

b. Recommended Wording:

c. Reason/Rationale for Recommendation:

6. REMARKS

7a. NAME OF SUBMITTER *(Last, First, MI)* – Optional	b. WORK TELEPHONE NUMBER *(Include Area Code)* – Optional
c. MAILING ADDRESS *(Street, City, State, ZIP Code)* – Optional	8. DATE OF SUBMISSION *(YYMMDD)*

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