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JSSG-2006
30 October 1998

DEPARTMENT OF DEFENSE

JOINT SERVICE SPECIFICATION GUIDE

AIRCRAFT STRUCTURES

This specification guide is for guidance only.

Do not cite this document as a requirement.

AMSC N/A FSG 15GP

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FOREWORD

JSSG RELEASE NOTE

The specification guides support the acquisition reform initiative, and is predicated on a performance based business environment approach to product development. As such it is intended to be used in the preparation of performance specifications. It is one of a set of specification guides. It is the initial release of this guide. In this sense this document will continue to be improved as the development program is accomplished.

1. This guide is approved for use by the all Departments and Agencies of the Department of Defense.

2. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should bde addressed to: ASC/ENSI, 2530 Loop Rd W, Wright-Patterson AFB OH 45433-7101, by using the Standardization Document Improvement Proposal (DD form 1426) appearing at the end of this document or by letter.

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APPENDIX A

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JOINT SERVICE SPECIFICATION GUIDE

AIRCRAFT STRUCTURES

GENERAL SPECIFICATION FOR

1. SCOPE

1.1 Scope.

This guide establishes the joint structural performance and verification requirements for the airframe. These requirements are derived from operational and maintenance needs and apply to the airframe structure which is required to function, sustain loads, resist damage and minimize adverse operational and readiness impacts during usage for the entire service life. This usage pertains to both land and ship based operations including take-off, catapult, flight, landing, arrestment, ground handling, maintenance, and flight and laboratory tests. This specification also provides for trade studies and analyses to identify and establish certain structural design parameters and criteria which, as a minimum, are necessary to enable the airframe to meet these structural performance requirements, consistent with the program acquisition plan for force level inventory and life cycle cost.

1.2 Application.

1.2.1 Program.

This specification applies to __________.

1.2.2 Aircraft.

This specification applies to ___________.

1.2.3 Aircraft structure.

This specification applies to metallic and nonmetallic air vehicle structures. The air vehicle structure, hereinafter referred to as the airframe, includes the fuselage, wing, empennage, landing gear, structural elements of the control systems, control surfaces, radomes, antennas, engine mounts, nacelles, pylons, in-flight refueling mechanism, carrier related apparatus/devices, structural operating mechanisms and structural provisions for equipment, payload, cargo (if applicable), personnel, and _______________.

1.3 Use.

This specification cannot be used for contractual purposes without supplemental information relating to the structural performance of the aircraft structures.

1.3.1 Structure.

The supplemental information required is identified by blanks within the specification.

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1.3.2 Instructional handbook.

The instructional handbook, which is contained in the appendix herein, provides the rationale for specified requirements, guidance for inclusion of supplemental information, a lessons learned repository, and ___________. This specification is meant to be tailored by filling in the blank elements according to the particular air vehicle's performance requirements and characteristics, with approriate supporting engineering justification. In the absence of such justification and acceptance, the recommendations in the handbook shall be used to fill in the blanks of this specification.

1.4 Deviations.

Prior to contract award, prospective contractors are encouraged to submit to the acquisition activity cost effective changes, substitutions and improvements to the requirements of this specification. Incorporation will depend upon the merits of the proposed change and the needs of the program. After contract award, changes will be accomplished in accordance with applicable contract specification change notice (SCN) procedures.

2. APPLICABLE DOCUMENTS

2.1 General.

The documents listed in this section are specified in sections 3 and 4 of this specification. This section does not include documents cited in other sections of this specification or recommended for additional information or as examples. While every effort has been made to ensure the completeness of this list, document users are cautioned that they must meet all specified requirements documents cited in sections 3 and 4 of the specification, whether or not they are listed.

2.2 Government documents.

2.2.1 Specifications, standards, and handbooks.

The following specifications, standards, and handbooks form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those listed in the issue of the Department of Defense Index of Specifications and Standards (DoDISS) and the supplement thereto, cited in the solicitation (see 6.2).

SPECIFICATIONS

Department of Defense

MIL-B-85110	Bar, Repeatable Release Holdback, Aircraft Launching, General Design Requirement for
NAEC-MISC-06900	Aircraft Carrier Reference Data Manual

STANDARDS

Department of Defense

MIL-STD-1374	Weight and Balance Data Reporting Forms for Aircraft (Including Rotorcraft)
MIL-STD-2066	Catapulting & Arresting Gear Forcing Functions for Aircraft Structural Design

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

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2.2.2 Other Government documents, drawings, and publications

The following other Government documents, drawing, and publications form a part of this document to the extent specified herein. Unless otherwise specified, the issues are those cited in the solicitation (see 6.2).

Department of Defense

Drawing 607770 Design Requirements, Catapulting Arrangements, Nose Gear Type Launch

(Application for copies should be addressed to: Commander, Code 4.1.4, Highway 547, Lakehurst NJ 08733-5100.)

2.3 Non-Government publications.

The following document(s) form a part of this specification to the extent specified herein. Unless otherwise specified, the issues of the documents which are Department of Defense (DoD) adopted are those listed in the issue of the DoDISS cited in the solicitation. Unless otherwise specified, the issues of documents not listed in the DoDISS are the issues of the documents cited in the solicitation (see 6.2).

(Application for copies should be addressed to: ______________________________.)

2.4 Order of precedence.

In the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

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3. REQUIREMENTS

(The instructional handbook, which is contained in the appendix herein, provides the rationale for specified requirements, guidance for inclusion of supplemental information, a lessons learned repository, and ___________. This specification is meant to be tailored by filling in the blank elements according to the particular air vehicle's performance requirements and characteristics, with appropriate supporting engineering justification. In the absence of such justification and acceptance, the recommendations in the handbook shall be used to fill in the blanks of this specification. In addition, specific paragraphs may be tailored by deletion or not applicable, by inserting "N/A" in parentheses following the number and title, or by rewriting of the paragraph by inserting "REWRITE" in parentheses following the number and title.)

3.1 Detailed structural design requirements.

The requirements of this specification reflect operational and maintenance needs and capabilities and are stated in terms of parameter values, conditions, and discipline (loads, flutter, etc.) requirements. The air vehicle shall have sufficient structural integrity to meet these requirements, separately and in attainable combinations.

3.1.1 Deterministic design criteria.

The deterministic structural design criteria stated in this specification are, as a minimum, those necessary to ensure that the airframe shall meet the detailed structural design requirements established in this specification. These criteria are also based on the requirements derived from the inherent operational, maintenance, engineering, and test needs of the aircraft such as the location of and access to equipment and the loading and unloading of cargo or payload. Each individual criterion established herein has been selected based upon historical experience with adjustments made to account for new design approaches, new materials, new fabrication methods, unusual aircraft configurations, unusual usage, planned aircraft maintenance activities, and any other significant factors. Trade studies and analyses supporting the substantiation of the adequacy of these criteria in meeting the specified and inherent design requirements, and their use in design details, shall be documented in accordance with the verification requirements in 4.1.1.

3.1.2 Probability of detrimental deformation and structural failure.

Only where deterministic values have no precedence or basis, a combined load-strength probability analysis shall be conducted to predict the risk of detrimental structural deformation and structural failure, subject to the approval of the procuring activity. For the design requirements stated in this specification, the airframe shall not experience detrimental structural deformations with a probability of occurrence equal to or greater than __________ per flight. Also, for these design requirements, the airframe shall not experience the loss of adequate structural rigidity or proper structural functioning such that flight safety is affected or suffer structural failure leading to the loss of the air vehicle with a probability of occurrence equal to or greater than ___________ per flight. Shipboard landings are per the multi-variate distribution of landing impact conditions of __________.

3.1.3 Structural integrity.

The air vehicle shall meet the structural integrity requirements of this specification. These integrity requirements shall apply to all parts of the air vehicle including the airframe, actuators,

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fairings, seals, films, coatings, etc. Critical parts may have additional requirements designed to control their quality, durability, and/or damage tolerance.

3.1.3.1 Parts classification.

All air vehicle parts and components shall be classified for criticality.

3.1.3.2 Fatigue/fracture critical parts.

Fatigue/fracture critical parts shall meet the requirements of 3.11, 3.12, and the control processes of 3.13.

3.1.3.3 Maintenance critical parts.

Maintenance critical parts shall meet the requirements of 3.11 and 3.12.

3.1.3.4 Mission critical parts.

In addition to the requirements of this specification, mission critical parts shall have special design critieria developed to meet the requirements of the air vehicle specification. In addition, special controls on quality, processes, and inspections may be required.

3.1.3.5 Fatigue/Fracture critical traceable parts.

Fatigue/fracture critical traceable parts shall meet the requirements of 3.11, 3.12, and the control process of 3.13.

3.2 General parameters.

The airframe shall have sufficient structural integrity to meet the required operational and maintenance capabilities reflected in the parameters of 3.2 and subparagraphs and attainable combinations of the parameters. These parameters are to be used in conjunction with the conditions and discipline requirements of this specification.

3.2.1 Airframe configurations.

The airframe configurations shall encompass those applicable to flight and ship-based/ground conditions and reflect authorized usage of the air vehicle.

3.2.2 Equipment. (_____)

The airframe shall support and react the loads and motion of all equipment required and expected to be carried by the air vehicle. This equipment includes ___________________.

3.2.3 Payloads. (_____)

The airframe shall support and react the loads and motions of payloads required and expected to be carried by the air vehicle. These payloads include __________________.

3.2.4 Weight distributions.

The air vehicle weight distributions shall be those required for operations and maintenance use.

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3.2.5 Weights.

The weights to be used in conducting the design, analysis, and test of the air vehicle are derived combinations of the operating weights, the defined payload, and the fuel configuration. These weights shall be the expected weight at Initial Operation Capability (IOC).

3.2.5.1 Operating weight.

The operating weight is the weight empty plus oil, crew, unusable fuel, and __________.

3.2.5.2 Maximum zero fuel weight.

The maximum zero fuel weight shall be the highest required weight of the loaded air vehicle without any usable fuel and is specified as the operating weight plus __________.

3.2.5.3 Minimum flight weight.

The minimum flight weight shall be the lowest weight required for flight and is specified as __________.

3.2.5.4 Basic flight design gross weight.

The basic flight design gross weight shall be the highest flight weight required for the maximum positive and minimum negative load factors of 3.2.9.1 maneuvering flight and is specified as the operating weight plus ___________.

3.2.5.5 Maximum flight weight.

The maximum flight weight shall be the highest weight required for flight and is specified as the operating weight plus ___________.

3.2.5.6 Landplane landing weight.

The landplane landing weight shall be the highest landing weight for the maximum land based sink rate and is specified as the operating weight plus ___________.

3.2.5.7 Maximum landing weight.

The maximum landing weight shall be the highest weight required for any landing and is specified as the operating weight plus ___________.

3.2.5.8 Maximum ground weight.

The maximum ground weight shall be the highest weight required for ramp, taxiway, and runway usage and is specified as the operating weight plus ____________.

3.2.5.9 Maximum take-off weight.

The maximum take-off weight shall be the highest required weight for flight usage at the time of lift-off and is specified as the operating weight plus __________.

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3.2.5.10 Maximum landing gear jacking weight.

The maximum landing gear jacking weight shall be the highest weight required for landing gear jacking and is specified as the operating weight plus ___________.

3.2.5.11 Maximum airframe jacking weight.

The maximum airframe jacking weight shall be the highest weight required for jacking on the airframe at locations other than the landing gear and is specified as the operating weight plus ____________.

3.2.5.12 Hoisting weight.

The hoisting weight shall be the highest weight required for hoisting at the designated hoisting points considering combinations of hoisting points and is specified as the operating weight plus _________.

3.2.5.13 Maximum catapult design gross weight. (____)

The Maximum Catapult Design Gross Weight shall be the maximum catapult launch weight to be used to determine maximum tow force and in determining maximum launch Constant Selector Valve (CSV) settings and is specified as the operating weight plus _____________.

3.2.5.14 Maximum catapult weight. (____)

The maximum catapult weight shall be the maximum launch weight for which shipboard launch is required within the structural limits of the airframe, wind over deck (WOD) capability and launch end speed of the ship system and is specified as the operating weight plus ____________.

3.2.5.15 Primary catapult mission weight. (____)

The primary catapult mission weight is the minimum weight used to determine the maximum horizontal acceleration used in setting launch bulletin limits and is specified as the operating weight plus ________________.

3.2.5.16 Carrier landing design gross weight. (____)

The carrier landing design gross weight shall be the maximum aircraft weight at which shipboard recovery can be initiated and shall be based on the ability to perform ___ passes and fly ____ nautical miles with _____ payload.

3.2.5.17 Barricade design gross weight. (_____)

The maximum weight at which shipboard barricade recovery can be initiated and is specified as the operating weight plus __________.

3.2.5.18 Other weight.

The air vehicle, fuel, and payload configuration to be used in determining the design weights for other conditions and the corresponding design conditions are as follows: ____________.

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3.2.6 The center of gravity.

The center of gravity envelopes shall be commensurate with the requirements in the detailed specification and all the weights in 3.2.5 plus and minus a tolerance to account for manufacturing variations, addition of planned equipment, variations in payload, flight attitudes, density of fuel, fuel system failures of 3.2.22, and __________.

a. The tolerance is ___________.

b. The envelope is ____________.

3.2.6.1 Lateral center of gravity position.

The lateral center of gravity envelope shall be commensurate with the requirements in the detailed specification and all weight defined in 3.2.5. The envelope shall consider all asymmetrical store loading conditions which result in the lesser of the following rolling moments:

a. times the maximum rolling moment attainable by loading each store station, with all possible combinations of pylons, adapters, launchers, racks and stores specified to be carried by that store station. As each store station is loaded, all other stations shall be empty of everything but an air worthy pylon.

b. Maximum attainable loading of one side of the aircraft with the other side empty of everything except air worthy pylons.

3.2.7 Speeds.

The following speeds and any attainable lesser speeds are applicable for ground and flight use of the air vehicle considering both required and expected to be encountered critical combinations of configurations, gross weights, centers of gravity, thrust or power, altitudes, and type of atmosphere and shall be used in the design of the airframe.

3.2.7.1 Level flight maximum speed, V_H.

The level flight maximum speeds shall be the maximum authorized continuous level flight speeds required and otherwise attainable by the air vehicle.

3.2.7.2 Dive speed, V_D. (______)

The dive speeds shall be the maximum authorized dive speeds necessary to perform the required missions and are __________________.

3.2.7.3 Limit speed, V_L.

The limit speeds shall be the maximum speeds of the air vehicle and are ____________.

3.2.7.4 Maneuver speed, V_A. (_____)

The maneuver speeds shall be the speeds authorized for full maneuvering load factor capability of 3.2.9.1 and are ______________________.

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3.2.7.5 Takeoff, approach, and landing limit speeds, V_{LF}.

The takeoff, approach, and landing limit speeds shall be the maximum authorized speeds associated with the operation of the landing gear and other devices for and during takeoff and landing operations. These speeds shall be high enough to provide the crew ample time to operate and control the devices with only nominal attitude and trim changes of the air vehicle flight and propulsion control systems. These speeds are ___________.

3.2.7.6 Lift-off limit speeds, V_{LO}.

The lift-off limit speeds shall be the maximum authorized and necessary ground speeds for the takeoff operations and are ___________.

3.2.7.7 Touch-down limit speeds, V_{TD}.

The touch-down limit speeds shall be the maximum authorized and necessary ground contact speeds for the landing operations and are __________.

3.2.7.8 Taxi limit speeds, V_T.

The taxi limit speeds shall be the maximum authorized and necessary ground speeds for ground operations on taxiways and ramps and are __________.

3.2.7.9 Gust limit speeds, V_G.

The gust limit speeds shall be the maximum authorized speeds for continued operation in turbulent air and are __________.

3.2.7.10 Maneuver stalling speeds, V_{S1}.

The maneuver stalling speeds shall be the minimum level flight speeds with flaps retracted.

3.2.7.11 Landing stalling speeds V_{SL}.

The landing stalling speeds shall be the minimum level flight speeds in the landing configuration with zero thrust.

3.2.7.12 System failure limit speeds, V_{SF}.

The maximum speeds for flight after detectable system failures of 3.2.22 from which recovery is expected shall be __________.

3.2.7.13 Shipboard recovery speed, V_{TDC}. (____)

This shall be the maximum deck touch-down speed for determining recovery bulletin limits based on the Carrier Landing Design Gross Weight, critical c.g. position and store loadings authorized for bring-back. This value used to determine structural landing criteria shall be based on design performance requirements and tropical day temperature.

3.2.7.14 Shipboard engaging speed, V_E. (____)

For structural airframe design this shall be equal to the "Shipboard Recovery Speed" less the average wind over deck plus a 3.1 sigma (P_O = .001) on engaging speed derived from aircraft survey data of similiar class aircraft.

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3.2.7.15 Shipboard launch end speed, V_C. (____)

This shall be the minimum launch end speed required not to exceed ________ feet of sink over the bow (summation of ship speed, natural winds, and catapult end speed).

3.2.7.16 Maximum brake speed, V_{HD}. (____)

This shall be the maximum allowable speed at which the arresting hook may be lowered during carrier operations and is ___________.

3.2.7.17 Emergency jettison speeds. (____)

The emergency jettison speeds of all stores or suspension equipment shall be the maximum authorized speeds necessary for safe release and are _________.

3.2.7.18 Selective jettison speeds. (____)

The selective jettison speeds of all stores or suspension equipment no longer required for performance of the missions are _________.

3.2.7.19 Store employment speeds. (____)

The release speeds for store employment shall be the maximum authorized speeds necessary to perform the required missions and are _________.

3.2.7.20 Other speeds.

Other speeds applicable to specified uses are __________________.

3.2.8 Altitudes.

The following altitudes and any attainable lesser altitudes are applicable for ground and flight use of the air vehicle considering required and expected to be encountered combinations of configurations, gross weights, centers of gravity, thrust or power, speeds, type of atmosphere, and the usage of 3.2.14 and shall be used in the design of the airframe.

3.2.8.1 Maximum flight altitude.

The maximum flight altitude shall be the maximum altitude authorized and necessary for flight operations.

3.2.8.2 Maneuver altitude. (______)

The maneuver altitude shall be the maximum altitude authorized and necessary for full load factor maneuvering capability of 3.2.9.1.

3.2.8.3 Maximum ground altitude.

The maximum ground altitudes shall be the maximum altitudes authorized and necessary for ground operations.

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3.2.9 Flight load factors.

The following flight load factors shall be the maximum and minimum load factors authorized for flight use and shall be used in the design of the airframe.

3.2.9.1 Basic flight design gross weight load factors.

The normal flight weight maximum and minimum load factors are _______________.

3.2.9.2 Maximum flight weight load factors.

The maximum flight weight maximum and minimum load factors are ________________.

3.2.9.3 Takeoff, approach, and landing load factors.

The takeoff, approach, and landing maximum and minimum load factors are ______________.

3.2.9.4 High drag load factors.

Load factors to be considered in the high drag configuration are _____________.

3.2.9.5 Air vehicle load factors after detectable system failures.

After recovery from any in-flight failure, as defined in 3.2.22, the allowable load factors for return to base shall be those which result in loads that do not exceed __________ of structural design limit loads.

3.2.9.6 Other flight load factors. (_______)

Other load factors applicable to specified flight uses are: _______________.

3.2.10 Land based and ship based aircraft ground loading parameters.

The airframe shall have sufficient structural integrity for the air vehicle to take-off, catapult, land, arrest, and operate on the ground or ship under the appropriate conditions of 3.4.2 and the parameters defined here-in, in attainable combinations, considering the required and expected combinations of the applicable parameters of 3.2 and 3.4. Lesser values of the following parameters are applicable in determining attainable combinations.

3.2.10.1 Landing sink speeds.

The maximum landing touchdown vertical sink speeds of the air vehicle center of mass to be used in the design of the airframe and landing gear shall not be less than:

a. Landplane landing design gross weight: ___________________.

b. Ship based landing design gross weight (_____):___________________.

c. Maximum land based landing weight: _________________.

3.2.10.2 Crosswind landings.

The crosswinds at take-off and landing shall be those components of surface winds perpendicular to the runway centerline or ship landing reference centerline. The landing gear loads resulting from crosswind operations shall be ____________________.

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3.2.10.3 Land based landing roll, yaw, pitch attitudes, and sink speed.

The landing touchdown roll, yaw, pitch attitude, and sink speed combinations shall be based on a joint probability within an ellipsoid with axes of roll, yaw, and pitch. The extremes on these axes are:

a. Roll angle. Plus _________ and minus _____________.

b. Yaw angle. Plus _________ and minus _____________.

c. Pitch angle. Mean plus _________ and minus _____________.

d. Sink Speed. Mean plus ___________ and minus ____________.

3.2.10.4 Taxi discrete bumps, dips and obstructions.

The bumps and dips shall be of the _________ wave lengths, amplitudes, and shape.

a. Maximum ground weight, slow speeds up to: ____________.

b. Maximum ground weight, speeds at and above: ________________.

3.2.10.5 Jacking wind loading conditions.

The maximum combination of wind loading and air vehicle load factor conditions that shall be allowed during the jacking of the air vehicle are __________.

3.2.10.6 Catapult takeoff. (_______)

a. Maximum catapult design gross weight_____________.

b. Maximum catapult weight_____________.

c. Primary catapult mission weight_____________.

d. Maximum N_X (rigid c.g.) ______________.

e. Maximum horizontal tow force ____________.

f. Repeatable release holdback bar load ___________.

3.2.11 Limit loads.

The limit loads, to be used in the design of elements of the airframe subject to deterministic design criteria, shall be the maximum and most critical combination of loads which can result from authorized ground and flight use of the air vehicle, including maintenance activity, the system failures of 3.2.22 from which recovery is expected, a lifetime of usage of 3.2.14, and all loads whose frequency of occurrence is greater than or equal to __________ per flight. All loads resulting from the requirements of this specification are limit loads unless otherwise specified.

3.2.12 Ultimate loads.

Ultimate loads not derived directly from ultimate load requirements of this specification shall be obtained by multiplying the limit loads by appropriate factors of uncertainty. These ultimate loads shall be used in the design of elements of the airframe subject to a deterministic design criteria. These factors of uncertainty and the circumstances where they are to be used are __________.

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3.2.12.1 Shipboard landing design loads.

Design loads are those for which compliance with the deformation criteria in 3.2.13 is required.

3.2.13 Deformations.

Temperature, load, and other induced structural deformations/deflections resulting from any authorized use and maintenance of the air vehicle shall not:

a. Inhibit or degrade the mechanical operation of the air vehicle or cause bindings or interferences in the control system or between the control surfaces and adjacent structures.

b. Affect the aerodynamic characteristics of the air vehicle to the extent that performance guarantees or flying qualities requirements cannot be met.

c. Result in detrimental deformation, delamination, detrimental buckling, or exceedance of the yield point of any part, component, or assembly which would result in subsequent maintenance actions.

d. Require repair or replacement of any part, component, or assembly.

e. Reduce the clearances between movable parts of the control system and adjacent structures or equipment to values less than the minimum permitted for safe flight.

f. Result in significant changes to the distribution of external or internal loads without due consideration thereof.

3.2.14 Service life and usage.

The following parameters are applicable and reflect required operational and maintenance capability for air vehicle structures service life and usage conditions.

3.2.14.1 User identified requirements.

The number of flights, flight hours, shipboard and field operations, landings, mission data, etc. shall be:

a. _________ Service life (Flight hours). In service use, ninety percent of all aircraft shall project to meet or exceed this value for durability and all aircraft shall meet this value with respect to safety.

b. For time dependent design functions, a life of ___________ years.

c. _________of_________ Ground-air-ground cycles (flights).

d. ________of_________ Field taxi runs.

e. _________of_________ Field takeoffs.

f. _________of_________ Catapult launches.

g. Landings.

(1) _________of________Field.

(2) _________of________ FCLP (Field Carrier Landing Practice).

(3) _________of________ Carrier arrested.

(4) _________of________ Carrier touch-and-go.

h. (_____) mission profiles as specified in ____________.

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i. (_____) mission mix as specified in ______________.

j. Other service life and usage as specified in ______.

3.2.14.2 Representative basing concept.

Occurrences and durations of taxi, turns, pivoting, braking, fuel and payload loading and unloading, engine trim runs, towing, and other ground/carrier operations shall be as shown in _______________.

3.2.14.3 Repeated loads sources.

All sources of repeated loads shall be considered and included in the development of the service loads spectra and shall not detract from the airframe service life. The following operational and maintenance conditions shall be included as sources of repeated loads:

a. Maneuvers. The maneuver load factor spectra are _______________.

b. Gusts. The gust loads spectra shall be ______________.

c. Suppression Systems. Systems which enhance ride qualities (_____):

(1) Active oscillation control.

(2) Gust alleviation.

(3) Flutter supression.

(4) Terrain following.

d. Vibration and aeroacoustics. The vibration and aeroacoustic loads spectra and associated duration shall reflect the operational usage of the aircraft as required in 3.5 and 3.6.

e. Landings. The landing loads spectra shall reflect operational parameters and conditions applicable to landings from 3.2 and 3.4.2, respectively. The sink speed spectra are ___________________.

f. Buffet. All static and dynamic sources including the following:

(1) Buffet due to non-linear flow caused by the shedding of vortices during high angle of attack operations.

(2) Buffet due to transonic shock instabilities.

g. Other ground loads. The taxi, braking, brake release, pivoting, turning, towing, and miscellaneous ground loads spectra shall include vertical, lateral, and longitudinal loads and accelerations resulting from ground/carrier operations of 3.2.14. These spectra shall include:

(1) Hard and medium braking occurrences per full-stop landings of ________________.

(2) Pivoting occurrences of _____________________.

(3) Taxiway, ramp, takeoff, and landing roll-out vertical loads spectra resulting from operation on surfaces with roughness of _____________________.

h. Pressurization. (________) The flight number and magnitude of pressurization cycles shall be based on the number of flights, missions, etc. of 3.2.14 plus ground pressure

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checks. The cockpit and cabin maximum pressures shall be determined using nominal settings of the regulator valves.

i. Repeated operation of movable structures. Impact, operational, and residual loads occurring from the normal operation of movable structures shall be included in applicable loads spectra.

j. Store loads. (____) Carriage and employment loads shall be included in applicable loads spectra.

k. Heat flux. (_____) The repeated heat flux time histories are _______________.

l. Other loads. (_____).

3.2.14.4 Other requirements.

Other operational and maintenance requirements affecting the airframe service life or usage are _________.

3.2.14.5 Airframe structure inspection.

By design, the airframe structure shall not require inspection during the service life specified in 3.2.14.

3.2.14.6 Design durability service loads/spectrum.

This spectrum shall represent the service life and usage defined in 3.2.14.1 through 3.2.14.4, adjusted for historical data, potential weight growth and future aircraft performance at least to initial operation capability (IOC), to reflect severe utilization within the design utilization distribution and such that 90 percent of the fleet will be expected to meet the service life. A flight-by-flight analysis spectrum shall be developed for design durability analysis and a flight-by-flight test spectrum shall be developed for verification tests to verify the structural requirements of 3.11.

3.2.14.7 Design damage tolerance service loads/spectrum.

This spectrum shall represent the service life and usage defined in 3.2.14.1 through 3.2.14.4, adjusted for historical data, potential weight growth and future aircraft performance at least to initial operation capability (IOC), to reflect baseline utilization within the design utilization distribution and such that the average aircraft usage of the fleet will be expected to meet the service life. A flight-by-flight analysis spectrum shall be developed for design damage tolerance analysis and a flight-by-flight test spectrum shall be developed for verification tests to verify the structural requirements of 3.12.

3.2.15 Atmosphere.

The airframe shall be designed to operate in atmospheres _______________.

3.2.16 Chemical, thermal, and climatic environments.

The airframe shall be designed to operate in the environments defined below:

a. Ground environments: _______________________.

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b. Shipboard environments: Sulfur and nitrogen oxide containing gasses from ship stacks and aircraft exhaust combined with 3.5 percent sodium chloride sea spray to form highly acidic moisture films of pH 2.4 - 4.0. Relative humidity of 70 percent to 100 percent conditions exist simultaneously with sand and dust particle concentrations ranging from 1.32 x 10^{-4} to 4.0 x 10^{-6} lbs/ft^3.

c. Air environments: ___________________________.

d. Man-made environments: _____________________.

e. Usage generated environments: ________________.

f. Maintenance generated environments: ____________________.

3.2.17 Power or thrust loads.

The power or thrust of the installed propulsion system shall be commensurate with the ground and flight conditions of intended use, including system failures of 3.2.22, and the capabilities of the propulsion system and crew. The thrust loads attainable shall include all thrust loads up to the maximum. These loads shall include engine transients due to both normal engine operation as well as the engine system failures of 3.2.22 and __________.

3.2.18 Flight control and stability augmentation devices.

In the generation of loads, flight control and automatic control devices, including load alleviation and ride control devices, shall be in those operative, inoperative, and transient modes for which use is required or likely or due to the system failure conditions of 3.2.22 and __________.

3.2.19 Materials and processes.

Materials and processes shall be selected in accordance with the following requirements so that the airframe meets the operational and support requirements.

a. Relevant producibility, maintainability, supportablilty, repairability, and availability experience with the same, or similar, materials processes shall be a governing factor for suitability of the airframe design. Environmentally conditioned tests must be performed at the appropriate development test level to meet relevant design conditions.

b. Material systems and materials processes selected for design shall be stable, remain fixed, and minimize unique maintenance and repair practices in accordance with the specified operational and support concepts.

c. Material systems and materials processes (including radioactive materials and processes) shall be environmentally compliant, compliant with best occupational safety and health practices, and minimize hazardous waste generation.

3.2.19.1 Materials.

The materials used in the airframe shall be commensurate with the operational and support requirements for the airframe. Whenever materials are proposed for which only a limited amount of data is available, the acquisition activity shall be provided with sufficient background data so that a determination of the suitability of the material can be made. The allowable structural properties shall include all applicable statistical variability and environmental effects, such as exposure to climatic conditions of moisture and temperature; exposure to corrosive and corrosion causing environments; airborne or spilled chemical warfare agents; and maintenance

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induced environments commensurate with the usage of the airframe. Specific material requirements are:

a. Average values of crack growth data (da/dN) shall be used in the crack growth analysis if the variation of crack growth data is a typical distribution. Reference 3.10.4.4 for a non-typical distribution.

b. Minimum values of fracture toughness shall be used for residual strength analysis.

c. "A" basis design allowables shall be used in the design of all critical parts (see definitions 6.1.23 through 6.1.23.4). "A" basis design allowables shall also be used in the design of structure not tested to ultimate load in full scale airframe static testing. "B" basis design allowables may be used for all other structure which include: ____________________________.

d. "S" basis design allowables are acceptable for design when "A" or "B" basis allowables are not available, provided they are specified in a governing industry/government document that contains quality assurance provisions at the heat, lot, and batch level in the as-received material condition. Appropriate test coupons shall accompany the material in the as-received condition and shall be subject to testing for verification of minimum design properties after final processing.

e. ________________________________.

3.2.19.2 Processes.

The processes used to prepare and form the materials for use in the airframe as well as joining methods shall be commensurate with the material application. Further, the processes and joining methods shall not contribute to unacceptable degradation of the properties of the materials when the airframe is exposed to operational usage and support environments. Specific material processing requirements are:

a. ______________________.

b. ______________________.

3.2.20 Finishes.

The airframe and its components shall be finished in compliance with the following requirements.

a. Environmental Protection. __________________. Specific organic and inorganic surface treatments and coatings used for corrosion prevention and control must be identified and established.

b. Visibility. ______________________.

c. Identification. _________________.

d. Aerodynamically smooth exterior surfaces. _____________________.

e. Other. _________________________.

3.2.21 Non-structural coatings, films, and layers.

Coatings (organic and inorganic), films, and layers applied or attached to the interior or exterior of the airframe or to subsystem components shall not degrade the structural integrity of the air vehicle below the minimum required by this specification. The coatings, films, and layers shall

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be sufficiently durable to withstand all flight, ground, and maintenance environments and usage without requiring maintenance during __________________.

3.2.22 System failures.

All loads resulting from or following the single or multiple system failures defined below whose frequency of occurrence is greater than or equal to the rate specified in 3.2.11 shall be limit loads. Subsequent to a detectable failure, the air vehicle shall be operated with the flight limits of 3.2.5, 3.2.7.10, and 3.2.9.5. Loads resulting from a single component failure shall be designed for as limit load, regardless of probability of occurrence.

a. Tire failures. (_____).

b. Propulsion system failures. (_____).

c. Radome failures. (_____).

d. Mechanical failures. (_____).

e. Hydraulic failures. (_____).

f. Flight control system failures. (_____).

g. Transparency failures. (_____).

h. Hung stores. (_____).

i. Other failures. (_____). ________________________.

3.2.23 Lightning strikes and electrostatic charge.

The following electricity phenomena occurring separately shall not degrade, damage, or cause to fail critical components of the airframe when airborne such that safe, continued, and controlled flight is in question and, additionally, shall not cause injury to support personnel servicing or maintaining the air vehicle.

3.2.23.1 Lightning protection. (____)

The airframe shall be capable of withstanding _______________.

3.2.23.2 Electrostatic charge control. (____)

The airframe shall be capable of adequately controlling and dissipating the buildup of electrostatic charges for ________________.

3.2.24 Foreign object damage (FOD). (____)

The airframe shall be designed to withstand the FOD environments listed below. These FOD environments shall not result in the loss of the air vehicle or shall not incapacitate the pilot or crew with a frequency equal to or greater than _________________ per flight. These FOD environments shall not cause unacceptable damage to the airframe with a frequency equal to or greater than _______________ per flight.

3.2.24.1 Bird FOD. (____).

The airframe shall be designed to withstand the impact of _______________ pound birds with the corresponding air vehicle speeds of _______________ KTAS in a manner consistent with

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the normal flight without loss of the air vehicle or the incapacitation of the pilot or crew. The airframe shall be designed to withstand the impact of _______________ pound birds with the corresponding air vehicle speeds of _______________ KTAS with no unacceptable damage. Unacceptable damage is _______________.

3.2.24.2 Hail FOD. (____).

The airframe shall be designed to withstand the impact of _______________ hail with the corresponding air vehicle speeds of _______________ KTAS in a manner consistent with normal flight without loss of the air vehicle or the incapacitation of the pilot or crew. The airframe shall be designed to withstand the impact of _______________ hail with the corresponding air vehicle speeds of _______________ KTAS with no unacceptable damage. Unacceptable damage is _______________.

3.2.24.3 Runway, taxiway, and ramp debris FOD. (____).

The airframe shall be designed to withstand the impact of _______________ FOD during any phase of taxi, takeoff, and landing without loss of the air vehicle or the incapacitation of the pilot or crew. The airframe shall be designed to withstand the impact of _______________ FOD during any phase of taxi, takeoff, and landing with no unacceptable damage. Unacceptable damage is _____________.

3.2.24.4 Other FOD. (____).

__________________________.

3.2.25 Producibility.

Producibility must be designed into the aircraft structure from the beginning and must be a design influence throughout the design process.

3.2.26 Maintainability.

Maintainability must be designed into the aircraft from the beginning and must be a design influence throughout the design process. The maintainability shall be consistent with the user's planned operational use, maintenance concepts, and force management program. High or moderate maintenance items must be accessible and/or replaceable to facilitate maintenance.

3.2.27 Supportability.

Supportability must be designed into the aircraft structure from the beginning and must be a design influence throughout the design process. Supportability shall be consistent with the user's present and projected maintenance concepts, maintenance facilities, and force management programs. Projected EPA requirements must be considered.

3.2.28 Repairability.

Repairability must be designed into the aircraft from the beginning and must be a design influence throughout the design process. Repairability is required to support production, maintain the fleet, and maximize operational readiness by repairing battle damage. High or moderate maintenance items and items subject to wear must be repairable.

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3.2.29 Replaceability/interchangeability.

Appropriate levels of replaceability and/or interchangeability must be designed into the aircraft structure to meet the requirements of operational readiness, maintenance, supportability, logistic concepts, repairability, and producibility. Major structural items which are interchangeable are ____________________.

3.2.30 Cost effective design.

Cost effective design concepts and practices must be used from the beginning of the aircraft design and must be a design influence throughout the design process. Balancing acquisition cost, life cycle cost, performance, and schedule is an integral part of an integrated product development concept. An integrated design approach which strives for a producible cost effective design is critical to achieving the optimal balance of design, life cycle cost, schedule, and performance. A stable design with stable processes is required for accurate cost assessments.

3.3 Specific design and construction parameters.

The following specific features, conditions and parameters, marked applicable, reflect required operational and maintenance capability of the airframe. These items have a service life, maintainability, or inspection requirement different than the parent airframe as identified in 3.2.14. Historical maintainability experience with the same, or similar, design and construction shall be a governing factor for suitability of the airframe design.

3.3.1 Doors and panels. (____)

The structural integrity of doors and panels, including seals shall be sufficient for their intended use, including that resulting from the air vehicle usage of 3.2.14. The use of any door/panel shall not be inhibited by interference with other parts of the air vehicle or require special positioning of the air vehicle or any part thereof during normal use. For ground maintenance, all doors/panels shall be fully usable with the landing gear struts in any position. The door/panel cut-out support structure shall meet the in-flight residual strength requirements of 3.12.2.

3.3.1.1 Access doors and components. (___)

Access doors and components with one or more quick-opening latches or fasteners shall not fail, open, vibrate, flap or flutter in flight with ________________________. This requirement also applies to structural doors and panels. The most critical combinations of latches or fasteners are to be designed for left unsecure conditions.

3.3.2 Doors and ramps mechanisms of pressurized compartments. (___)

The latching mechanisms used on doors and ramps shall not be capable of indicating closed and locked and the air vehicle pressurized if any part of the latching mechanism or associated structure is not performing its intended function. Visual inspection of each latch, for proper closure and locking shall be provided on doors and ramps using two or more latches per operating mechanism or control. Doors and ramps mechanisms, including hinges, locks and stops, shall meet the damage tolerance requirements for fail-safe multiple load path structure of 3.12.2.2.

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3.3.3 Ramps (___)

Deflections, deformations, and motions of any ramp shall not interfere with other parts or components of the air vehicle during normal use of the ramp and air vehicle. Ramps shall meet the in-flight residual strength requirements of 3.12.2.

3.3.3.1 Engine inlet ramps or equivalent compression surfaces. (___)

Water shall not collect or be trapped in these ramps during flight or ground use such that ice can form and damage the ramp or subsequently shed into the flight control surfaces or engines causing damage to the surfaces or engine.

3.3.3.2 Cargo ramps - loading and unloading. (___)

Any ramp used for loading or unloading of cargo defined in 3.2.2 shall be capable of sustaining all vertical, lateral, and longitudinal loads from initial contact, alignment, and traverse of the ramp by the cargo. The cargo shall contact the ramp:

a. At speeds up to ___________.

b. At any horizontal angle to the ramp within + ________ degrees.

c. And align with and traverse the ramp at speeds up to __________.

3.3.3.3 Cargo ramps - in-flight. (___)

Any ramp used to support cargo in-flight shall ______________.

3.3.4 Cargo floors. (___)

Cargo floors shall be capable of supporting cargo distributions of _________.

3.3.5 Transparencies. (___)

The structural design of the following transparencies shall permit replacement of the transparencies within the man-hours indicated: __________________.

3.3.6 Tail bumper. (___)

A tail bumper shall be provided.

a. Type: _______________.

b. Capability: ______________.

3.3.7 Tail hook. (___)

A tail hook shall be provided.

a. Type of hook and shoe: _________________________.

b. Type of engagements: _________________________.

c. Arrestment system and cable: _________________________.

d. Surface in front of arrestment cable: _________________________.

e. Capability: _________________________.

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3.3.8 Vents and louvers. (____)

If necessary to maintain their required usefulness, equipment and structure behind and near vents and louvers shall be designed for the effects of flow through the vents and louvers during conditions of normal and reverse flows. Thermal, sand abrasion, rain, ice, etc. foreign object damage effects are to be covered for _______________.

3.3.9 Cavities. (___)

Structures, equipment, and equipment provisions in, adjacent to, or immediately downstream of cavities open to the airstream during flight shall be designed for the effects of oscillatory air forces. Pressure oscillations within and downstream of the cavity shall be minimized by addition of airflow control devices.

3.3.10 Armor. (___)

Armor shall be provided to _____________.

3.3.11 Refueling provisions. (___)

The area around the aerial refueling receptacle or aerial refueling probe system shall be free of obstructions and shall not need to be replaced for ________________.

3.3.12 Cables and pushrods. (____)

Cables and pushrods shall meet the following requirements: _________________________.

3.3.13 Airframe bearings and pulleys. (____)

Airframe bearings and pulleys shall meet the following requirements: _______________.

3.3.14 Fasteners. (____)

Fastener selection, installation, quality assurance (including screw threads and screw thread quality verification techniques) and joining methods shall be commensurate with the specified airframe operational and support requirements.

3.3.15 Integral fuel tanks and lines. (___)

Fuel tanks and lines which are integral with or considered a part of the structure of the air vehicle shall meet the following structural integrity requirements: _______________.

3.3.16 Nuclear weapons retention. (___)

The retention of nuclear weapons requirements are __________. The support and suspension system shall meet the damage tolerance requirements for fail-safe multiple load path structure of 3.12.2.2.

3.3.17 Rapid decompression. (___)

The safety of flight structure shall possess in-flight evident residual strength (3.12.2) to withstand rapid decompressions from which recovery is expected. If the pressurized structure has several compartments separated by partitions, bulkheads, floors, or combinations thereof, the safety of flight portions of the structure shall withstand the pressure differential caused by

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the sudden release of pressure in any compartment during any approved operating or maintenance usage of the air vehicle. Venting and other means of controlling the differential pressure between compartments is permitted. The structure, including nonstructural compartment bulkheads, wall and ceiling panels, doors, etc., shall not cause injury to properly restrained personnel within the compartments. The probable size, shape, and location of the opening that causes sudden decompression shall be rationally established. Such failures shall not degrade, damage, or cause to fail any other components of the flight control, fuel, hydraulic, or electrical systems, such that safe, continued, and controlled flight is in question. Sources of openings shall include:

a. All openings that result from system failures defined in 3.2.22.

b. Subcritical cracks or arrested critical cracks originating from fatigue or induced flaws.

c. The following occurrences and any others considering the operational experience of similar air vehicles performing similar missions:

(1) Bird strikes.

(2) The largest portions of any engine or propeller following disintegration.

(3) Failure of other subsystems.

d. Other.

3.3.18 Design provisions for ship-based suitability. (____)

3.3.18.1 Wing design provisions for ship-based suitability (____)

3.3.18.1.1 Wing folding or sweeping (ship-based aircraft). (____)

Deck stowage space shall be minimized by providing means for folding the wings, or alternatively, sweeping them in conjunction with a variable sweep design.

3.3.18.2 Empennage design for ship-based suitability. (____)

The tips for vertical fin, horizontal stabilizer, or other empennage surfaces must be detachable to facilitate repair. If empennage surfaces are folding, they shall be designed such that necessary maintenance can be performed with the surfaces in the folded position.

3.3.18.3 Cockpit/cabin design for ship-based suitability. (____)

For aircraft designed for catapulting, means shall be provided for crew members to brace themselves during catapult operations. Drains shall be provided at low points of cockpits.

3.3.18.4 Equipment compartment ship-based suitability requirements. (____)

Equipment compartments (bomb bays, electronic bays, etc) shall be accessible without the requirement for support equipment such as work stands or ladders.

3.3.18.5 Landing gear ship-based suitability requirements. (____)

For aircraft with nose wheel type gear arrangements, the landing gear geometry shall be in accordance with Navy Drawing 607770. Landing gears of ship-based aircraft shall include provisions to prevent damage due to repeated sudden extension of the landing gear as the

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wheels pass over the deck edge subsequent to catapulting, bolter, or touch and go. Also, the landing gear shall not contain features such as sharp projections or edges that could cause failure of the arrestment barricade. Landing gear wells shall be designed to allow a 3.5 percent increase in tire size due to over inflation. To preclude striking catapult shuttles and PLAT camera covers, the centers of nose wheel axles shall clear the deck by at least 6.5 inches (in.) when the tires are flat. Tires shall be selected such that neither the nose or main landing gear tires are not fully deflected during catapult. If the nose landing gear has a stored-energy type strut, the energy stored in the shock absorber shall be sufficient to provide rotation of the aircraft to flight attitude at the end of the deck run in the event that one or both nose gear tires have failed during the catapult.

The wheel brake hydraulic system shall be capable of providing adequate braking for deck handling without engine operation or external power packages, and be able to perform at least 10 applications of the normal brake before a hand pump or other means must be utilized to repressurize the brake system. A pressure indicator shall be provided in the pilot's cockpit. A parking brake shall be provided as well. A "park-on" cockpit warning system or an automatic park brake release system shall be provided to preclude "brakes-on" during catapulting.

3.3.19 Repeatable release holdback bar (_____).

The holdback bar shall restrain the aircraft against aircraft engine thrust, catapult tensioning force, and ship motion. The holdback bar shall be of the repeatable release type and shall be designed in accordance with MIL-B-85110. The configuration of the lower portion (deck end) of the holdback bar shall conform to the requirements of NAEC Drawing 607770. The design load for the aircraft holdback bar is __________.

3.3.20 Other design and construction parameters. (____)

___________.

3.4 Structural loading conditions.

The airframe operational and maintenance capability shall be in accordance with the following structural loading conditions in conjunction with the detailed structural design requirements of 3.1 and the general parameters of 3.2.

3.4.1 Flight loading conditions.

Flight loading conditions are essentially realistic conditions based on airframe response to pilot induced or autonomous maneuvers, loss of control maneuvers, and turbulence. These realistic conditions shall consider both required and expected to be encountered critical combinations of configurations, gross weights, centers of gravity, thrust or power, altitudes, speeds, and type of atmosphere and shall be used in the design of the airframe. Flight loading conditions shall reflect symmetric and asymmetric flight operations and are established for both primary and secondary structural components by careful selection of flight parameters likely to produce critical applied loads. Symmetric and asymmetric flight operations shall include symmetric and unsymmetric fuel and payload loadings and adverse trim conditions. The following conditions reflect required flight operations capability of the airframe.

3.4.1.1 Symmetric maneuvers.

These maneuvers shall be performed with and without a ________ roll rate command. The analyses shall include tolerances to account for known discrepancies such as air data system

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errors, attitude errors, control system lags, fuel sequence, actuator performance, and rigging. These tolerances shall be applicable until the loads flight test data has validated the maneuver simulation.

a. Steady pitching maneuvers of __________________.

b. Abrupt pitching maneuvers with longitudinal control displacements of ____________.

3.4.1.2 Asymmetric maneuvers.

These maneuvers shall be fully coordinated and, alternately, uncoordinated maneuvers. The analyses shall include tolerances to account for known discrepancies such as air data system errors, attitude errors, control system lags, fuel sequence, actuator performance, and rigging. These tolerances shall be applicable until the loads flight test data has validated the maneuver simulation.

a. Level flight rolls of ___________________.

b. Rolling pull-outs of __________________.

c. Steady pitching maneuvers with abrupt roll (_____) ______________________.

d. Steady rolling maneuvers with abrupt pitch (_____) _______________.

e. Roll rate capability after recovery from an in-flight system failure of 3.2.22 shall not be less than ___________.

3.4.1.3 Directional maneuvers.

The analyses shall include tolerances to account for known discrepancies such as air data system errors, attitude errors, system lags, fuel sequence, actuator performance, and rigging. These tolerances shall be applicable until the loads flight test data has validated the maneuver simulation.

a. Rudder kicks of _______________.

b. Rudder reversals of _______________.

c. Target tracking (____). _______________.

d. Sideslips of _______________.

e. Unsymmetrical thrust with zero sideslip (_____). ____________.

f. Engine failure (____). _______________.

g. Engine-out operation (____). _______________.

3.4.1.4 Evasive maneuvers. (____)

The analyses shall include tolerances to account for known discrepancies such as air data system errors, attitude errors, system lags, fuel sequence, actuator performance, and rigging. These tolerances shall be applicable until the loads flight test data has validated the maneuver simulation.

a. Jinking maneuvers of _______________.

b. Missile break maneuvers of _______________.

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3.4.1.5 Other maneuvers. (______)

The analyses shall include tolerances to account for known discrepancies such as air data system errors, attitude errors, system lags, fuel sequence, actuator performance, and rigging. These tolerances shall be applicable until the loads flight test data has validated the maneuver simulation.

a. Stalls (_____) ___________________.

b. Departures (____) ___________________.

c. Spins (_____) ___________________.

d. Tail slides (___) ___________________.

e. ___________________.

3.4.1.6 Turbulence.

The airframe shall be capable of operating in the atmosphere with vertical and lateral gusts representative of those expected to be encountered during:

a. (___) Required missions and a gust exceedance rate of _________. The power spectrum of the expected turbulence is defined by _________ and the turbulence field parameters are as shown in __________. The airframe shall not have strength less than a level established with limit gust velocity values Y_d / $\bar{A}$ of ______________.

b. (___) Wake turbulence ________________.

c. (___) Gust plus maneuver ________________.

d. (___) Other turbulence conditions ________________.

3.4.1.7 Aerial refueling. (_____)

3.4.1.7.1 Tanker. (____)

The flight loading condition requirements for tanker air vehicles during refueling are _______________________.

3.4.1.7.2 Receiver. (____)

The flight loading condition requirements for receiver air vehicles during refueling are ________________.

3.4.1.8 Aerial delivery. (___)

The aerial delivery flight loading conditions are ________________.

3.4.1.9 Speed and lift control. (____)

3.4.1.9.1 Speed control. (____)

The flight loading conditions for speed controlling devices are ____________.

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3.4.1.9.2 Lift control. (_____)

The flight loading conditions for lift controlling devices are ____________.

3.4.1.10 Braking wheels in air. (______)

________________.

3.4.1.11 Extension and retraction of landing gear. (_____)

__________________.

3.4.1.12 Pressurization.

The pressure differentials to be used in the design of pressurized portions of the airframe, including fuel tanks, shall be the maximum pressure differentials attainable during flight within the design flight envelope, during ground maintenance, and during ground storage or transportation of the air vehicle. These maximum pressure differentials shall be the maximum attainable with the normal operation of the pressure regulation system nominal settings plus manufacturing tolerance or the maximum pressure differentials attainable during or following the system failures of 3.2.22 which occur at a rate greater than or equal to that specified in 3.2.11. These maximum pressure differentials shall include both positive, inside-to-outside, and negative, outside-to-inside pressure differentials as well as pressure differentials across pressure boundaries separating adjacent internal compartments. Where appropriate, these pressures shall be combined with other flight loads to obtain the most critical combination of flight and pressurization loads. The internal stresses and strains arising from the pressurization loads shall not be assumed to be relieving from other flight loads unless the probability of a loss of pressurization is less than the rate specified in 3.2.11. Similarly, structural stabilization derived from pressurization shall not be used to achieve required structural performance capabilities unless the probability of the loss of pressurization is less than the rate specified in 3.2.11.

a. For normal flight operations, the maximum pressure differentials attainable shall be increased by a factor not less than _______________ when acting separately or in combination with 1g level flight loads. These maximum pressure differentials shall include the effects of undetectable or uncontrollable system failures of 3.2.22.

b. For emergency flight operations or when combined with maximum maneuver flight loads, the maximum pressure differentials attainable shall be increased by a factor not less than _______________. These maximum pressure differentials shall include the effects of detectable and controllable system failures of 3.2.22.

c. For ground operations including maintenance, the maximum pressure differentials attainable shall be increased by a factor not less than ______________. These maximum pressure differentials shall include the effects of the system failures of 3.2.22 occurring during maintenance, storage, fueling, and ground transportation of the air vehicle.

3.4.1.13 Aeroelastic deformation effects. (____)

Aeroelastic deformations shall be included when determining the final airload distributions.

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3.4.1.14 Dynamic response during flight operations. (_____)

The dynamic response of the air vehicle resulting from the transient or sudden application of loads shall be included in the determination of design loads.

3.4.1.15 Other flight loading conditions. (____) ___________________.

3.4.2 Ground loading conditions.

Ground loading conditions are generally not truly realistic conditions, but situations which should result in design loads. These conditions shall consider both required and expected to be encountered critical combinations of configurations, gross weights, centers of gravity, landing gear/tire servicing, external environments, thrust or power, and speeds and shall be used in the design of the airframe. Ground operations shall include symmetric and unsymmetric fuel and payload loadings and adverse trim conditions. The following conditions reflect required ground operations and maintenance capability of the air vehicle. Forcing functions and time histories for shipboard carrier catapult and arresting gear are provided in MIL-STD-2066. Barricade deceleration is as shown in NAEC-MISC-06900. The structural integrity of the airframe shall be adequate for the air vehicle to perform as required.

3.4.2.1 Taxi.

a. Dynamic taxi conditions. ________________.

b. 2.0g Taxi. (____) Taxi conditions at all critical combinations of ____________________.

3.4.2.2 Turns.

a. Turns on ramps at speeds up to ________________.

b. Turns on taxiways at speeds up to ________________.

c. Runway turn-offs at speeds up to ________________.

3.4.2.3 Pivots. (____)

a. The pivot points are ________________.

b. The power or thrust levels shall be ________________.

3.4.2.4 Braking.

a. Braking during taxi on ________________.

b. Braking during turns on ________________.

c. Pivoting. (____) Braking during pivoting of ________________.

d. Braking after an aborted takeoff on ________________.

e. Braking after landing of ________________.

3.4.2.5 Takeoffs.

a. Hard surface runways. (____) Takeoffs from ________________.

b. Semi-prepared runways. (____) Takeoffs from ________________.

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c. Unprepared surfaces. (____) Takeoffs from ________________.

d. Takeoff brake release of ________________.

e. Catapult launch. (____) ________________.

f. Catapult assist ramps. (____) ________________.

g. Assisted takeoff. (____) ________________.

h. Ski-jump. (____) ________________.

i. Other takeoff conditions. (____) ________________.

3.4.2.6 Landings.

a. Hard surface runways. (_____) Landings on ___________________.

b. Semiprepared runways. (_____) Landings on ________________.

c. Unprepared surfaces. (_____) Landings on _______________.

d. Arrestment. (_____) ___________________.

e. Decelerating devices. (____) _______________.

f. Other landing conditions. (____) ________________.

3.4.2.7 Dynamic response during ground/ship-based operations. (______)

The dynamic response of the air vehicle resulting from ground operations and transient or sudden application of loads shall be included in the determination of design loads. In addition, the air vehicle shall be free from any static or dynamic instabilities.

a. Dynamic response conditions. _____________.

b. Shimmy. During all ground operations (taxi, take-off, and landing), all landing gears as installed in the air vehicle shall be free from shimmy, divergence, and other related gear instabilities for all attainable combinations of configurations, ground operation speeds, loadings, and tire pressures. This requirement shall apply for both normal and failure operations. For the nose gear, the steering system shall be considered ON and also failed or OFF. The design of the landing gear systems as installed shall meet the damping requirement of ________________.

3.4.2.8 Ski equipped air vehicles. (____)

a. Frozen skis. ________________.

b. Ski load distribution conditions. ________________.

3.4.2.9 Maintenance.

a. Towing. (_____) ____________________.

b. Jacking. (_____) ____________________.

c. Hoisting. (_____) ____________________.

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3.4.2.10 Ground winds.

a. Ground operations. ______________.

b. Maintenance. ______________.

c. Parked, unattended. ______________.

d. Tied-down. ______________.

e. Jet blast. (____). ______________.

3.4.2.11 Crashes. (____)

The airframe shall be able to withstand crashes so as to protect personnel to the extent reflected by the following ultimate loading conditions and parameters. The airframe shall not inhibit personnel egress from an airframe within ________________.

a. Seat installations. The seat occupant shall not be injured by airframe/seat support installation deformations or failures resulting from ____________.

b. Fuel tanks and installations. The airframe shall not inhibit fuel containment for conditions of ___________.

c. Fixed and removable equipment. ___________________.

d. Cargo. (____). ___________________.

e. Litters. (____). ___________________.

f. Bunks. (_____). ___________________.

3.4.2.12 Ditching. (_____)

The structural integrity of the air vehicle shall be maintained during ditching operations in order to protect personnel and allow successful egress and deployment of survival equipment. The water pressures specified in ________ shall be used for structural design.

3.4.2.13 Other ground loading conditions. (____)

3.4.3 Vibration and aeroacoustics.

Vibration and aeroacoustic loadings shall be combined with the flight and ground loads of 3.4.1 and 3.4.2. Vibration and aeroacoustic loads shall be as required by 3.5 and 3.6.

3.5 Aeroacoustic durability.

The airframe structure shall operate in the aeroacoustic environments which are commensurate with the required parameters of 3.2 and 3.3, and rational combinations thereof without failure as described herein. Aeroacoustic loads sources include: ________________.

3.5.1 Structure.

The airframe structure shall withstand the aeroacoustic loads and the vibrations induced by aeroacoustic loads for the service life and usage of 3.2.14 without cracking or functional impairment. For design, an uncertainty factor of ___ shall be applied on the predicted aeroacoustic sound pressure levels. For design fatigue life, a factor of ___ shall be applied on the exposure time derived from the service life and usage of 3.2.14.

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3.5.2 Internal noise. (___)

Sound pressure levels in areas of the aircraft occupied by personnel during flight shall be controlled as required by human factors requirements. These shall be __________. Sound treatments shall be integrated with the airframe structure and with airframe subsystems to achieve an optimum balance of weight, cost, and complexity.

3.6 Vibration.

The airframe shall operate in the vibration environments which are commensurate with the required parameters of 3.2, 3.3, 3.4, and rational combinations thereof. Environmental effects such as temperature and humidity shall be included where applicable. Where required, vibration control measures such as damping or isolation shall be incorporated into the air vehicle. There shall be no fatigue cracking or excessive vibration of the airframe structure or components. Excessive vibrations are those structural displacements which result in components of the air vehicle systems not being fully functional. The structure and components shall withstand, without fatigue cracking, the vibrations resulting from all vibration sources for the service life and usage of 3.2.14. Vibration sources include: _______________.

3.7 Aeroelasticity.

The airframe shall operate in the flight environment which is commensurate with the general parameters of 3.2 and the failures of 3.7.3. The airframe shall meet the following requirements to preclude any aeroelastic related phenomena from degrading the required operational and maintenance capability of the airframe.

3.7.1 Aeroelastic stability.

The airframe in all configurations of the air vehicle shall be free from flutter, divergence, and other related aeroelastic or aeroservoelastic instabilities 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 airframe shall meet the following stability design requirements.

a. Airspeed margin: The equivalent airspeed, V_e, margin of safety at all points on the V_L/M_L envelope of the air vehicle, both at constant Mach number, M, and separately, at constant altitude, shall be not less than ________.

b. Damping: For any critical flutter mode or for any significant dynamic response mode for all altitudes and flight speeds from minimum cruising speeds up to V_L/M_L, the total (aerodynamic plus structural) damping coefficient, g, shall be not less than ____________.

3.7.1.1 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 or sustained limited amplitude instabilities of all critical modes under all flight conditions for normal and failure operating conditions of the actuating systems.

a. If circuit stiffness of control surfaces or tabs is utilized to prevent any aeroelastic instability, safe free play limits and maximum allowable inertia properties shall be established which shall not be exceeded during the service life of the airframe. These free play limits shall be as specified in 3.7.4.

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b. If mass balancing of control surfaces or tabs is utilized to prevent any aeroelastic instability, mass balance design requirements shall be established. These requirements shall include balance weight installation stiffness, static and repeated design loads for the balance weight installation, and mass balance tolerance for inclusion in maintenance manuals. In addition, the damage tolerance requirements of 3.12 are applicable to the balance weight installation. The static and repeated design loads for the balance weights and the adjacent supporting structure shall be ____________.

c. In the event that mass balance or rigidity criteria are impracticable, two parallel hydraulic dampers may be used to prevent any aeroelastic instability of a control surface, tab, and any other movable component which is exposed to the airstream. In addition, maximum free play limits, and minimum and maximum damper capability limits shall be established for the dampers.

3.7.1.2 Divergence.

Aerodynamic surfaces and components of the air vehicle shall not aeroelastically diverge.

3.7.1.3 Buzz. (___)

Control surfaces and parts thereof shall not buzz.

3.7.1.4 External store carriage. (___)

The airframe shall be designed to prevent flutter, divergence, sustained limited amplitude instabilities, and other related aeroelastic or aeroservoelastic instabilities when combinations of prescribed stores are carried on the air vehicle. The stability design requirements of 3.7.1a, 3.7.1b, and 3.7.2 shall apply on the limit speed (V_L/M_L) envelope specified for the air vehicle with stores.

3.7.1.5 Panel flutter. (___)

External, inlet, transparency, and other aerodynamically loaded panels shall be designed to prevent flutter and sustained limited amplitude instabilities, and satisfy the stability design requirements of 3.7.1a and 3.7.1b.

3.7.1.6 Transonic aeroelastic phenomena (___)

Lifting surface or other air vehicle components shall be designed to meet the stability design requirements of 3.7.1a and 3.7.1b when exposed to shock induced separation oscillations or other related aeroelastic instability phenomena peculiar to the transonic flight regime.

3.7.1.7 Whirl flutter. (___)

For air vehicles equipped with propeller, or proprotor engines, the propeller, powerplant, mounting systems, and pylons in combination with other components of the air vehicle, shall be designed to prevent whirl flutter.

3.7.1.8 Other controls and surfaces. (___)

Air vehicle components which are exposed to the airstream shall be designed to prevent any aeroelastic instability. These components shall include, but are not limited to, leading edge

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flaps, trailing edge flaps, spoilers, dive brakes, scoops, landing gear doors, weapon bay doors, ventral fins, movable inlet ramps, movable fairings, and blade antennas.

3.7.2 Aeroservoelasticity.

Interactions of air vehicle systems, such as the control systems coupling with the airframe, shall be controlled to prevent the occurrence of any aeroservoelastic instability. The operative states (on and off) of the systems shall be commensurate with the uses authorized in the flight manual as applicable throughout the full flight envelope. The air vehicle structural modes shall have the following stability margins for any single flight control system feedback loop at speeds up to V_L/M_L.

a. A gain margin of at least __________.

b. And separately, a phase margin of at least ______________.

3.7.3 Fail-safe stability.

After each of the failures listed below, the air vehicle shall be free from flutter, divergence, and other related aeroelastic or aeroservoelastic instabilities. The stability design requirements of 3.7.1a, 3.7.1b, and 3.7.2 shall be met after each of these failure conditions. In addition, this fail-safe criteria shall include air vehicle augmentation system failures and any other failures that occur at a rate equal to or more frequent than the rate specified in 3.1.2 for loss of adequate structural rigidity or structural failure leading to the loss of the air vehicle.

a. Failure, malfunction, or disconnection [except those specifically identified in 3.7.3.c(1) and 3.7.3.c(2)] of any single element or component 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 3.7.1a, 3.7.1b, and 3.7.2 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 air vehicle. In addition, the damage tolerance requirements of 3.12 shall apply.

(1) Failure of any single element in any hinge mechanism and its supporting structure of 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 air vehicles 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 or pitch rigidity of the propeller rotational axis.

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(3) Absence of propeller aerodynamic forces resulting from the feathering of any single propeller, and for air vehicles 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 3.7.3d(1) and 3.7.3d(2), above.

3.7.4 Free play of control surfaces and tabs.

Detail design shall assure that normal wear of components, control surfaces and tabs, and actuating systems will not result in values of free play greater than those specified below throughout the service life of the air vehicle. Components having an adequately established wear life may be replaced at scheduled intervals as approved by acquisition activity. However, all replacements shall be included in the wearout replacement budget established for the overall air vehicle. The following free play limits shall apply ___________.

3.7.5 Environmental effects - aeroelasticity.

The physical characteristics and properties of the control surfaces, tabs, and other components of the airframe shall not be changed by exposure to any natural or man-made environment throughout the service life of the airframe.

3.8 Required structure survivability - nuclear. (___).

a. The threat environment, resultant threat effects, air vehicle orientation, configuration, and mission/operating conditions are defined in ______________.

b. The gust and overpressure loads are limit loads. The damage tolerance requirements of 3.12 are applicable.

c. The operational survivability and hardness requirements for structural integrity of the airframe, threat damage tolerance, structural shielding, and structural provisions for nonstructural shielding as a result of exposure to the specified nuclear environment are:

(1) Primary structure ______________________.

(2) Flight control surfaces ______________________.

(3) Windshield/Canopy ______________________.

(4) Other ______________________.

d. Post damage availability. For combat damaged airframe structure and successful return of the air vehicle, the damaged structural parts shall be capable of being repaired, replaced, or interchanged with fully serviceable parts within the air vehicle post combat availability time specified in _____________________.

3.9 Required structure survivability - nonnuclear. (____).

a. The threat environment, resultant threat effects, air vehicle orientation, configuration, and mission/operating conditions are defined in _____________________.

b. The damage tolerance requirements of 3.12 are applicable.

c. The operational survivability requirements for structural integrity of the airframe, threat damage tolerance, and structural provisions for nonstructural shielding and armor as a result of exposure to the specified nonnuclear environment are:

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(1) Primary structure ______________________.

(2) Flight control surfaces _____________________.

(3) Windshield/Canopy ______________________.

(4) Other _____________________.

d. Post damage availability. For combat damaged airframe structure and successful return of the air vehicle, the damaged structural parts shall be capable of being repaired, replaced, or interchanged with fully serviceable parts within the air vehicle post combat availability time specified in ______________________.

3.10 Strength.

The airframe strength shall be adequate to provide the operational and maintenance capability required commensurate with the general parameters of 3.2 and 3.3 without detrimental deformations of 3.2.13 at 115 percent limit or specified loads and without structural failure at ultimate loads. The airframe strength shall also be adequate to meet the requirements of 3.1.2.

3.10.1 Material properties.

Strength related material property requirements are contained in 3.2.19.1.

3.10.2 Material processes.

Strength related material processing requirements are contained in 3.2.19.2.

3.10.3 Internal loads.

Internal loads of structural members within the airframe shall react the external loads generated by the air vehicle during operation and maintenance functions. Load paths shall be configured and controlled to be as direct as practical through the proper locating of primary structural members, selecting of materials, and sizing of members. The effects of panel buckling, material yield, and fastener tolerances on internal load distributions shall be considered.

3.10.4 Stresses and strains.

Stresses and strains in airframe structural members shall be controlled through proper sizing, detail design, and material selections to satisfactorily react all limit and ultimate loads. In laminated composites, the stresses and ply orientation are to be compatible and residual stresses of manufacturing are to be accounted for, particularly if the stacking sequence is not symmetrical.

3.10.4.1 Fitting factor.

For each fitting and attachment whose strengths are not proven by limit and ultimate load tests in which actual stress conditions are simulated in the fitting and surrounding structure, the design stresses values shall be increased in magnitude by multiplying these loads or stress values by a fitting factor. This fitting factor and the conditions for its use are as follows: __________________.

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3.10.4.2 Bearing factor.

When a bolted joint with clearance (free fit) is subjected to relative rotation under limit load or shock and vibration loads, the design stress values shall be increased in magnitude by multiplying a bearing factor times the stress values. This bearing factor and the conditions for its use are as follows: _______________.

3.10.4.3 Castings.

Castings shall be classified and inspected, and all castings shall conform to applicable process requirements. A casting factor of ________ shall be used. The factors, tests, and inspections of this section must be applied in addition to those necessary to establish foundary quality control. The use of castings or C/HiPed parts for primary or critical applications or castings with a casting factor less than 1.33 shall require successful completion of a developmental and qualification program approved by the procuring agency.

3.10.4.4 High variability structure.

Due to the nature of some structural designs or materials, high variability may be encountered around the nominal design. Such design features must have a minimum level of structural integrity at the acceptable extremes of dimensions, tolerances, material properties, processing windows, processing controls, end or edge fixities, eccentricities, fastener flexibility, fit up stresses, environments, manufacturing processes, etc. For the critical combinations of these acceptable extremes, the structure must have no detrimental deformation of the maximum once per lifetime load of 3.2.14.6 and no structural failure at 125 percent of design limit load and meet the requirements of 3.7.1. This requirement is in addition to the requirements of 3.10. Examples of such structure are stability critical compression structure, stability critical panels, some composites, resin transfer molded composite parts, castings with low castings factors, manufacturing critical parts, etc.

3.10.5 Static strength.

Sufficient static strength shall be provided in the airframe structure for reacting all loading conditions loads without degrading the structural performance capability of the airframe. Sufficient strength shall be provided for operations, maintenance functions, and any tests that simulate load conditions, such that:

a. Detrimental deformations, including delaminations, shall not occur at or below 115 percent of limit loads, or during the tests required in 4.10.5.3 and 4.10.5.4. The deformation requirements of 3.2.13 apply.

b. Rupture or collapsing failures shall not occur at or below ultimate loads.

c. All structure shall be designed to nominal dimensional values or 110 percent of minimum values, whichever is less.

d. Bonded structure shall be capable of sustaining the residual strength loads of 3.12.2 without a safety of flight failure with a complete bond line failure or disbond.

3.10.6 Dynamic strength.

Sufficient static strength and energy absorption capability shall be provided in the airframe to react all dynamic design landing conditions and reserve energy requirements. For land-based aircraft, the maximum sink speed is __________ and the reserve energy condition is _____________. For ship-based aircraft, the design requirements are _____________.

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3.10.7 Initial and interim strength flight releases.

Initial and, as needed, interim strength flight restrictions shall be established to maintain safe flight conditions until all structural validation testing has been successfully completed. The loads resulting from overshoots, upsets and the recovery from overshoots and upsets, and the loads during and following the system failures of 3.2.22 shall be included in the establishment of the flight restrictions.

a. For the initial strength flight release, flight restrictions shall be defined to restrict the air vehicles from experiencing loads greater than _______________ percent of limit loads. These loads shall be determined as a function of applicable structural validation testing with a factor of ____ or strength proof testing with a factor of ____.

b. Prior to the completion of all structural validation testing, interim strength flight releases shall be defined to permit flight up to the lesser of the strength envelope cleared through the strength proof testing of 4.10.5.4 or strength analyses with a risk mitigation factor of ___ to include accommodation of design complexity and available instrumentation values.

3.10.8 Final strength flight release.

Prior to final strength flight release for operation up to 100 percent of limit strength for either production air vehicles or flight test air vehicles not proof tested per 4.10.5.4, the airframe shall have exhibited ultimate load static test strength for ultimate loads, environmentally compensated as applicable, which reflect verified external limit loads, and validated and updated structural analyses.

3.10.9 Modifications.

Modifications to an existing air vehicle affecting the external or internal loads on the structure, as well as new or revised equipment installations, shall have adequate structural capability for the intended usage. This requirement also applies to unmodified structures whose loads have been increased because of the modification.

3.10.10 Major repairs, rework, refurbishment, and remanufacture.

The airframe of an existing air vehicle shall have adequate structural integrity and capability for the intended usage following major repairs, extensive reworks, extensive refurbishment, or remanufacture.

3.11 Durability.

The durability capability of the airframe shall be adequate to resist fatigue cracking, corrosion, thermal degradation, delamination, and wear during operation and maintenance such that the operational and maintenance capability of the airframe is not degraded and the service life, usage, and other provisions of 3.2.14 are not adversely affected. These requirements apply to metallic and nonmetallic structures, including composites, with appropriate distinctions and variations as indicated. Durability material properties shall be consistent and congruent with those properties of the same material, in the same component, used by the other structures disciplines. See 3.2.19.1.

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3.11.1 Fatigue cracking/delamination damage.

For one lifetime when the airframe is subjected to the environment and service usage specified in 3.2.14 except where it is desired to meet the special life provisions of 3.11.5, the airframe shall be free of cracking, delaminations, disbonds, deformations, or defects which:

a. require repair, replacement, inspection to maintain structural integrity, or undue inspection burden for ship based aircraft.

b. cause interference with the mechanical operation of the aircraft.

c. affect the aircraft aerodynamic characteristics.

d. cause functional impairment.

e. result in sustained growth of cracks/delaminations resulting from steady-state level flight or ground handling conditions.

f. result in water intrusion.

g. result in visible damage from a single ______ foot-pound (ft-lb) impact.

3.11.2 Corrosion prevention and control.

The airframe shall operate in the corrosion producing environments and conditions of 3.2.16. Corrosion (including pitting, stress corrosion cracking, crevice, galvanic, filiform, and exfoliation) which affects the operational readiness of the airframe through initiation of flaws which are unacceptable from a durability, damage tolerance, and residual strength viewpoint shall not occur during the service life and usage of 3.2.14. Corrosion prevention systems shall remain effective during the service life and usage of 3.2.14 in the environments and under the conditions of 3.2.16 for the periods indicated below. Specific corrosion prevention and control measures, procedures and processes must be identified and established commensurate with the operational and maintenance capability required of the airframe. Finishes shall also comply and be compatible with the requirements of 3.2.20. The following additional requirements apply:

a. Structure which is difficult to inspect, repair, or replace, or places an undue economic burden on the user, must comply with the requirements of 3.2.14 for the service life of the airframe.

b. Other structure for the period of ___________________.

3.11.3 Thermal protection assurance.

Thermal protection systems shall remain effective during the service life and usage of 3.2.14 in the environments and under the conditions of 3.2.16 for the periods indicated below. Finishes shall also comply and be compatible with the requirements of 3.2.20 and 3.11.2.

a. Structure which is difficult to inspect, repair, or replace for the service life of the airframe.

b. Other structure for the period of ___________________.

3.11.4 Wear and erosion.

The function of structural components, elements, and major bearing surfaces shall not be degraded by wear under the service life and usage of 3.2.14 for the periods indicated below. Leading edges, radomes, housings, and other protrusions shall not be degraded by erosion

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under the service life and usage of 3.2.14 for the periods indicated below. Bearings shall also comply and be compatible with the requirements of 3.3.13 and 3.11.2.

a. Structural surfaces which move for _______________.

b. Structural and maintenance access panels and other removable parts for ________.

c. Doors and ramps for _______________.

d. Other structure for _______________.

e. Leading edges for _______________.

f. Radomes for ________________.

g. Housings for _______________.

h. Other protrusions for ________________.

3.11.5 Special life requirement structure.

The following structural components shall comply with 3.11.1 and 3.11.2 for the periods indicated:

a. Limited life structure _________________.

b. Extra life structure. __________________.

3.11.6 Nondestructive testing and inspection (NDT/I).

NDT/I shall be utilized during the design, development, production, and deployment phases of the program to assure that the system is produced and maintained with sufficient structural integrity to meet performance requirements. Other requirements apply as appropriate: ___________.

3.12 Damage tolerance.

The damage tolerance capability of the airframe shall be adequate for the service life and usage of 3.2.14. Safety of flight and other selected structural components of the airframe shall be capable of maintaining adequate residual strength in the presence of material, manufacturing and processing defects and damage induced during normal usage and maintenance until the damage is detected through periodic scheduled inspections. All safety of flight structure shall be categorized into one of two categories, either slow crack growth or fail-safe. Single load path structure without crack arrest features shall be designated as slow crack growth structure. Structures utilizing multiple load paths and crack arrest features shall be designated as slow crack growth or fail-safe if sufficient performance and life cycle cost advantages are identified to offset the burdens of the appropriate inspectability levels of 3.12.2.2 or 3.12.2.3. These requirements apply to metallic and nonmetallic structures, including composites, with appropriate distinctions and variations as indicated. Damage tolerance material properties shall be consistent and congruent with those properties of the same material, in the same component, used by the other structure's disciplines. See 3.2.19.1. Damage tolerance requirements shall also be applied to the following special structural components:

a. Doors, ramps, and mechanisms (3.3.1, 3.3.2, and 3.3.3).

b. Nuclear weapons support and suspension structure (3.3.16).

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c. Other ____________________.

3.12.1 Flaw sizes.

The airframe shall have adequate residual strength in the presence of flaws for specified periods of service usage. These flaws shall be assumed to exist initially in the structure as a result of the manufacturing process, normal usage and maintenance, and after an in-service inspection. The specific flaw size requirements are detailed in ________________________.

3.12.2 Residual strength and damage growth limits.

The minimum required residual strength is specified in terms of the internal member load which the airframe must be able to sustain with damage present for the specified period of unrepaired service usage. The magnitude of this load shall be based on the overall degree of inspectability of the structure and is intended to represent the maximum load the internal member might encounter during a specified inspection interval or during a life time for noninspectable structure. This load (P_{xx}) is defined as a function of the specific degree of inspectability in ________________________.

a. Airframe loading spectrum. The airframe loading spectrum shall reflect required missions wherein the mission mix and the loads in each mission segment represent service usage. The required residual strength in terms of a maximum load must be greater than the maximum load expected during a given interval between inspections.

b. Fail-safe structure. For fail-safe structure, a minimum load (P_{yy}) shall be sustained by the remaining structure at the instant of load path failure of the primary member. This load, defined in 3.12.2, shall be sustained by the secondary member at any time during the inspection interval defined in 3.12.2. The magnitude of this load shall be the product of a dynamic factor and the load defined in 3.12.2 or the product of a dynamic factor and the internal member load at design limit load whichever is greater. The dynamic factor shall be ___________________.

c. Safety of flight structure. All safety of flight structure shall maintain the required residual strength in the presence of damage for specific period of unrepaired service usage as a function of design concept and degree of inspectability. Periods of unrepaired service usage shall be as specified below. For pressurized portions of the structure, the minimum required residual strength shall be based on a factor times the most negative and the most positive pressure differential attainable with normal cabin pressure system operation including expected external aerodynamic pressures and the effects of adverse tolerances combined with the appropriate required residual strength flight and landing loads.

(1) Periods of unrepaired service usage are shown in _______________.

(2) The pressure differential factor is __________________.

3.12.2.1 Slow crack growth structure.

The initial damage as defined in 3.12.1, which can be presumed to exist in the structure as manufactured, shall not grow to a critical size and cause failure of the structure due to the application of the maximum internal member load in two lifetimes of the service life and usage of 3.2.14 as modified by 3.12.2.a.

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3.12.2.2 Fail-safe multiple load path structure.

The degrees of inspectability for fail-safe multiple load path structure are in-flight evident, ground evident, walk-around, special visual, and depot/base level inspectable. The frequency of inspection for each of these inspectability levels shall be as below.

a. Initial inspection interval. The initial inspection interval and residual strength requirements are a function of the degree of inspectability of the primary element and shall be as shown in ____________.

b. Subsequent inspection intervals. The subsequent inspection intervals and residual strength requirements are also based on the degree of inspectability of the primary element and shall be as shown in ____________.

3.12.2.3 Fail-safe crack arrest structure.

The degrees of inspectability applicable to fail-safe crack arrest structure are the same as for fail-safe multiple load path structures defined in 3.12.2.2.

a. Initial inspection interval. The initial inspection interval and residual strength requirements are dependent on the particular geometry and the degree of inspectability and shall be as shown in _____________.

b. Subsequent inspection intervals. The subsequent inspection intervals and residual strength requirements are also based on the degree of inspectability of the primary damage and shall be as shown in ________________.

3.13 Durability and damage tolerance control.

A durability and damage tolerance control process shall be developed and maintained to ensure that maintenance and fatigue/fracture critical parts meet the requirements of 3.11 and 3.12.

3.14 Sensitivity analysis.

In service airframe structural life and life cycle cost shall not be significantly degraded by small variations in weight, maneuverability, usage, and _______.

3.15 Force management.

Force management will be applied to the airframe structure during operational use and maintenance of the air vehicle. A data acquisition system is required that collects, stores, and processes data which can be used to support the force management systems/program.

3.15.1 Data acquisition system provisions.

The data acquisition system shall be capable of recording operational usage data and shall be compatible with the airframe and all air vehicle systems when installed and used. The system shall interface with air vehicle systems and record the required data within required accuracies.

a. The data acquisition system shall meet the requirements of __________________.

b. The data acquisition system shall be installed in ______________________.

c. Ground/Data Handling ________________________.

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3.16 Production facilities, capabilities, and processes.

The manufacturing system shall have the facilities, capabilities, processes, and process controls to provide products of consistent quality that meet performance requirements. Key production processes shall have the stability, capability, and process controls to maintain key product characteristics within design tolerances and allowables.

3.17 Engineering data requirements.

Engineering data for all studies, analyses, and testing generated in accordance with the performance and verification requirements for loads, strength, rigidity, vibroacoustics, corrosion prevention and control, materials and processes selection, application and characterization, durability and damage tolerance, force management, and all other requirements of this specification (as identified) shall be documented. All data bases used to establish, assess, and support inspections, maintenance activities, repairs, modification tasks, and replacement actions for the life of the airframe shall be documented. Engineering data shall be consistent with and supportive of all milestones identified in the verification matrix activities identified in 4.0.

4. VERIFICATION.

The verification methodologies and the incremental process for completing the verification shall be identified in this section. The incremental verification shall be consistent with the expectations for design maturity expected at key decision points in the program. Table _____ provides a cross-reference between the requirements and the associated method and timing of the verification. This table is used to identify and verify that all requirements have an associated verification and expected level of verification for the key decision points.

4.1 Detailed structural design requirements.

The adequacy of the detailed structural design requirements contained in this specification shall be verified by the review of the documentation provided to substantiate the adequacy of the requirements. The air vehicle structure (airframe) shall be shown capable of achieving these requirements by applicable inspections, demonstrations, analyses, and tests. All verifications shall be the responsibility of the contractor; the Government reserves the right to witness or conduct any verification.

4.1.1 Deterministic design criteria.

The detailed structural design criteria shall reflect all of the requirements of this specification and those derived from operational, maintenance, engineering, and test needs. This criteria shall be verified by the review of the documentation provided to substantiate the adequacy of the criteria.

4.1.2 Probability of detrimental deformation and structural failure. (____).

The combined load-strength probability analyses shall be verified by the review of the documentation of the analyses and the review of supporting tests.

4.1.3 Structural integrity.

The requirements of 3.1.3 shall be met by analysis, inspection, demonstration, and test.

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4.1.3.1 Parts classification.

The requirements of 3.1.3.1 shall be met by analysis, documentation, and inspection.

4.1.3.2 Fatigue/fracture critical parts.

The requirements of 3.1.3.2 shall be met by analysis, documentation, inspection, and test.

4.1.3.3 Maintenance critical parts.

The requirements of 3.1.3.3 shall be met by analysis, documentation, and inspection.

4.1.3.4 Mission critical parts.

The requirements of 3.1.3.4 shall be met by examination, analysis, documentation, and inspection.

4.1.3.5 Fatigue/Fracture critical traceable parts.

The requirement of 3.1.3.5 shall be met by analysis, documentation, and inspection.

4.2 General parameters.

Analyses, tests, and inspections shall be in compliance with the following subparagraphs to show that the airframe meets the operational and maintenance capabilities required in 3.2.

4.2.1 Airframe configurations.

Contractor selected and acquisition agency approved configurations shall be verified during tests.

4.2.2 Equipment. (____).

The analyses, tests, and inspections required by this specification shall be sufficient to show that the airframe adequately supports and reacts all of the loads and motions of the equipment defined in 3.2.2.

4.2.3 Payloads. (___)

The analyses, tests, and inspections required by this specification shall be sufficient to show that the airframe has the ability to support and react all of the loads and motions of the payload defined in 3.2.3.

4.2.4 Weight distributions.

Weight distributions shall be verified by analyses. The following weight distributions shall also be verified by test: ____________________.

4.2.5 Weights.

The weight shall be assessed throughout the development program and validated by actual weighing.

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4.2.6 The center of gravity.

The center of gravity position of the weights in 3.2.5 shall be verified by actual weighing of an empty aircraft, fuel calibration, and analysis.

4.2.6.1 Lateral center of gravity position.

The lateral center of gravity position of the weights in 3.2.5 shall be verified by actual weighing of an empty aircraft, fuel calibration, and by analysis.

4.2.7 Speeds.

The speeds of 3.2.7 shall be shown to be attainable by the air vehicle by analyses and tests. The following speeds shall be shown to be attainable by the air vehicle by the indicated analyses/tests: ___________________.

4.2.8 Altitudes.

The altitudes of 3.2.8 shall be demonstrated to be attainable by the air vehicle by analyses and tests. The following altitudes shall be shown to be attainable by the air vehicle by the indicated analyses/tests: __________________.

4.2.9 Flight load factors.

The load factors of 3.2.9 shall be demonstrated to be attainable by the air vehicle by analyses and tests.

4.2.10 Land-based and ship-based aircraft ground loading parameters.

The air vehicle shall be shown capable of takeoff, landing, and operating under the conditions and parameters of 3.2.10 and 3.4.2 by analyses and tests.

4.2.11 Limit loads.

The limit loads shall be verified by analyses and tests.

4.2.12 Ultimate loads.

The ultimate loads shall be verified by inspection of strength analyses and tests.

4.2.13 Deformations.

That the air vehicle meets the deformation requirements of 3.2.13 shall be verified by analyses and tests.

4.2.14 Service life and usage.

The airframe structures service life and usage capability required by 3.2.14 shall be verified by analyses and tests. The requirement of 3.2.14.5 shall be verified by analysis.

4.2.15 Atmosphere.

Analyses and tests shall verify that the airframe can operate in the atmospheres of 3.2.15.

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4.2.16 Chemical, thermal, and climatic environments.

Analyses and tests shall verify that the complete airframe can operate in the environment of 3.2.16.

4.2.17 Power or thrust.

Analyses and tests shall verify that the power or thrust used is commensurate with the intended use requirements of 3.2.17.

4.2.18 Flight control and stability augmentation devices.

Analyses and tests shall verify that the control devices modes of operation are commensurate with the requirements of 3.2.18.

4.2.19 Materials and processes.

Inspections, analyses, and tests shall verify that the materials and processes selected are in compliance with the requirements of 3.2.19. The following requirements also apply:

a. Materials and processes development and characterization and the selection process must be documented. Second source materials (when established as a program requirement) must be qualified and demonstrated through testing to have equivalent performance and fabrication characteristics as the selected baseline material.

b. Materials and processes characteristics for critical parts (see definitions in 6.1.23) shall comply with the requirements of the parts control processes as specified in 3.13.

c. Environmental compliance with all applicable environmental statutes and laws for all materials systems and processes selected must be verified. This shall include life cycle management of hazardous materials.

4.2.19.1 Materials.

The materials used in the airframe and their properties shall be validated by inspections, analyses, and tests to verify that they are in compliance with the requirements of 3.2.19.1. Standardized test methods used to establish metallic and composite material systems properties shall be used, when available. When such standardized methods are not available, a program shall be undertaken to explore and develop standardized test methods. All test methods used in establishing material system performance shall be documented and submitted for procuring activity review.

4.2.19.2 Processes.

The processes and joining methods applied to the materials used in the airframe shall be validated by inspections, analyses, and tests to verify that they are in compliance with the requirements of 3.2.19.2.

4.2.20 Finishes.

Analyses and tests shall verify that the airframe finishes are in compliance with the requirements of 3.2.20.

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4.2.21 Non-structural coatings, films, and layers.

Analyses and tests shall verify that the airframe non-structural coatings are in compliance with the requirements of 3.2.21. Inspection and repair methods for the coatings, films, and layers shall be provided. Further, methods of nondestructive inspection shall be provided for inspecting the structure behind or beneath the coatings, films and layers for cracks, failures, damage, corrosion, and other structural integrity anomalies. In particular, if the inspections of 4.11.1.2.2.d and 4.12.1 are applicable to the structure behind or beneath the coatings, films, and layers, the coatings, films, and layers shall not preclude or impede the performance of the durability and damage tolerance inspections. If the coatings, films, or layers are attached by adhesive bonding, a positive bond control system shall be used to minimize the probability of occurrence of a very-low-strength bond and adequate in-process controls during fabrication and final non-destructive inspection techniques shall be established to minimize the probability of bond failure.

4.2.22 System failures.

Analyses and tests shall verify that the airframe structure complies with the failure requirements of 3.2.22.

4.2.23 Lightning strikes and electrostatic charge.

Analyses and tests shall verify that the airframe structure complies with the lightning strike requirements of 3.2.23.

a. Lightning protection. (___) Analysis and tests shall verify that the airframe structure complies with the lightning protection requirements of 3.2.23a.

b. Electrostatic charge control. (___) Analyses and tests shall verify that the airframe structure complies with the electrostatic charge control requirements of 3.2.23b.

4.2.24 Foreign object damage (FOD). (___)

Analyses shall be used to verify that the airframe structure complies with the foreign object damage requirements of 3.2.24. Testing shall be required as appropriate.

4.2.25 Producibility.

It must be demonstrated that manufacturing is an integral part of the design process. Producibility demonstrations are required for new or unproven design, construction, or manufacturing concepts to minimize the production risk. Producibility should be a factor in structural design trade studies.

4.2.26 Maintainability.

It must be demonstrated that maintainability is an integral part of the design process. Maintainability demonstrations are required for new or unproven designs, construction, or material systems to minimize the maintenance risk. Maintainability should be a factor in structural design trade studies.

4.2.27 Supportability.

It must be demonstrated that supportability is an integral part of the design process. Supportability demonstrations are required for new or unproven designs, construction, or

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material systems to minimize the supportability risk. Supportability should be a factor in structural design trade studies.

4.2.28 Repairability.

It must be demonstrated that repairability is an integral part of the design process. Structural repair manuals are required by the user to maintain and support the aircraft. Repairability demonstrations are required for new or unproven designs, construction, or material systems to minimize the support risk. Items subject to wear must be able to accommodate refurbishment or repairs such as oversize bushings or fasteners. Repairability should be a factor in structural design trade studies.

4.2.29 Replaceability/interchangeability.

Interfaces must be identified and controlled on replaceable and/or interchangeable parts. Interchangeable parts must be documented and interchangeability verified by demonstration. The impact on replaceability/interchangeability must be evaluated as a factor in structural design trade studies.

4.2.30 Cost effective design.

The airframe should be designed to cost using allocated cost requirements from higher level specifications. Design trades should be made against these allocated costs or a reallocation of costs considering acquisition cost and life cycle cost. A stable design and process is required to minimize the cost assessment risk.

4.3 Specific design and construction parameters.

Inspections, analyses, and tests as noted below shall verify that the airframe structure complies with the design and construction requirements of 3.3.

4.3.1 Doors and panels. (___)

Preliminary and final drawings shall contain sufficient detail to show that all doors are fully usable for all applicable operational and maintenance conditions in compliance with the requirements of 3.3.1. Tests shall show compliance with the clearance requirements of 3.3.1. Damage tolerance analyses and tests shall verify that the damage tolerance requirements of 3.3.1 are met.

4.3.1.1 Access doors and components. (___)

Analyses and tests shall verify that access doors and components meet the requirements of 3.3.1.1.

4.3.2 Doors and ramps mechanisms of pressurized compartments. (___)

Preliminary and final drawings shall show the details of the latching mechanisms and the means whereby the indicating and operating requirements of 3.3.2 are met. Analyses and tests shall show compliance with the latching and non-latching requirements of 3.3.2. Damage tolerance analyses and tests shall verify that the damage tolerance requirements of 3.3.2 are met.

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4.3.3 Ramps. (___)

Analyses and tests shall verify that ramps comply with the requirements of 3.3.3.

4.3.4 Cargo floors. (___)

Analyses and tests shall verify that cargo floors comply with the requirements of 3.3.4.

4.3.5 Transparencies. (___)

Analyses and tests using full scale representative articles of transparencies shall verify the replacement times of 3.3.5.

4.3.6 Tail bumper. (___)

Analyses and tests shall verify that the tail bumper has the capability to perform as required by 3.3.6.

4.3.7 Tail hook. (___)

Dynamic analyses shall show that the tail hook will function as required by 3.3.7. Tests shall verify that the tail hook will engage the arrestment cable, perform as required, and meet the requirements of 3.3.7.

4.3.8 Vents and louvers. (___)

Analyses and tests of gas temperatures and airflows through vents and louvers onto equipment and structure behind and near vents and louvers shall verify that the requirements of 3.3.8 are met.

4.3.9 Cavities. (___)

The details of the protection of equipment and equipment provisions in cavities shall be shown on preliminary and final drawings. Analyses and tests shall verify that the requirements of 3.3.9 are met.

4.3.10 Armor. (___)

Details of the location and amount of armor shall be shown on preliminary and final drawings. Analyses and tests shall verify that the requirements of 3.3.10 are met.

4.3.11 Refueling provisions. (___)

Preliminary and final drawings shall show that the required area around the aerial refueling receptacles or aerial refueling probe system is free of obstructions. Analyses, inspections, and tests shall verify that adequate clearance, strength, and impact durability exists for the structure in the area around the refueling receptacle in compliance with the requirements of 3.3.11.

4.3.12 Cables and pushrods. (___)

Analyses, inspections, and tests shall verify that the requirements of 3.3.12 are met.

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4.3.13 Airframe bearings and pulleys. (___)

Analyses, inspections, and tests shall verify that the requirements of 3.3.13 are met.

4.3.14 Fasteners. (___)

A combination of analyses, inspections, and tests shall verify that the requirements of 3.3.14 are met.

4.3.15 Integral fuel tanks and lines. (___)

Analyses and tests shall verify that the requirements of 3.3.15 are met.

4.3.16 Nuclear weapons retention. (___)

Analyses and tests shall verify that the requirements of 3.3.16 are met.

4.3.17 Rapid decompression. (___)

Analyses and tests shall verify that the airframe structure complies with the requirements of 3.3.17.

4.3.18 Design provisions for ship-based suitability. (____)

4.3.18.1 Wing design provisions for ship-based suitability. (____)

The contractor shall perform design checks to ensure that the requirements of 3.3.18.1 are met early enough in the design process to preclude development cost and schedule penalty.

4.3.18.2 Empennage design for ship-based suitability. (____)

During engineering development, the contractor shall ensure that the requirements of 3.3.18.2 are met by the design.

4.3.18.3 Cockpit/cabin design for ship-based suitability. (____)

During engineering development, the contractor shall ensure that the requirements of 3.3.18.3 are met by the design.

4.3.18.4 Equipment compartment ship-based suitability requirements. (____)

Contractor should perform and document human factors studies to ensure that all equipment bays can be reached without need for ground support equipment.

4.3.18.5 Landing gear ship-based suitability requirements. (____)

Barricade requirements shall be demonstrated by test. Otherwise requirements shall be verified through the design review process early in the engineering development process.

4.3.19 Repeatable release holdback bar. (____)

Analyses and tests shall verify that the repeatable release holdback bar has the capability to perform as required by 3.3.19.

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4.3.20 Other design and construction parameters. (___)

Analyses, inspections, and tests shall verify that the requirements of 3.3.20 are met.

4.4 Structural loading conditions.

The loading conditions and criteria of 3.4 shall be detailed and included in the detailed structural criteria of 3.1.1. Analyses and tests shall verify that the airframe can operate in the flight and ground environment associated with the operational use as required by 3.4.

a. Analyses.

(1) Flight loads analyses. ___________________.

(2) Ground loads analyses. ___________________.

(3) Aerodynamic heating analyses. (_____) ___________________.

(4) Other analyses. (___) ___________________.

b. Wind tunnel tests.

(1) Force model tests. (___) ___________________.

(2) Pressure model tests. (___) ___________________.

(3) Aeroelastic model tests. (___) ___________________.

(4) Other model tests. (___) ___________________.

c. Flight and ground tests.

(1) Flight loads measurements. (___) ___________________.

(2) Ground loads measurements. (___) ___________________.

(3) Temperature measurements. (___) ___________________.

(4) Other measurements tests. (___) ___________________.

4.4.1 Flight loading conditions.

Analyses and tests shall be of sufficient scope to determine and verify the loads resulting from and commensurate with the flight loading conditions of 3.4.1.

4.4.2 Ground loading conditions.

Analyses and tests shall be of sufficient scope to determine and verify the loads resulting from and commensurate with the ground loading conditions of 3.4.2. Dynamic analyses and tests are also required to verify that the air vehicle is free from dynamic instabilities which could impact ground/ship based operations.

4.4.3 Vibration and aeroacoustics.

Vibration and aeroacoustics loadings shall be combined with flight and ground loads in accomplishing 4.4, 4.4.1, and 4.4.2. Vibration and aeroacoustic loads shall be as required by 4.5 and 4.6.

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4.5 Aeroacoustic durability.

Analyses and tests shall verify that the airframe can operate in the aeroacoustic environment associated with operational use as required by 3.5.

4.5.1 Structure.

Analyses and tests shall verify that the structure meets the requirements of 3.5.1.

4.5.1.1 Analyses.

Near field aeroacoustic loads shall be predicted for the air vehicle for the service life and usage of 3.2.14 and the sources listed in 3.5. Model tests are required where reliable predictions of the environment cannot be made. Analytical predictions of the fatigue life shall be made for all structure exposed to aeroacoustic loads.

4.5.1.2 Tests.

4.5.1.2.1 Fatigue tests.

Aeroacoustic fatigue tests shall be performed utilizing the uncertainty factors on sound pressure level and duration specified in 3.5.1. Other simulated environments (such as temperature and pressure differential) combined with the sonic environment shall be imposed when applicable.

4.5.1.2.1.1 Component tests.

Aeroacoustic fatigue tests of structural components are required to verify the aeroacoustic fatigue analyses of components including those structures where the fatigue life cannot be adequately predicted, such as new materials or structures of unusual configuration.

4.5.1.2.1.2 Full-scale tests. (_____)

Tests of the airframe are required to verify the aeroacoustic durability for the environments based on the flight and ground surveys of 4.5.1.2.2.

4.5.1.2.2 Ground and flight aeroacoustic measurements.

Aeroacoustic loads and dynamic response measurements are required for all areas of the airframe designated fatigue critical by analyses of 4.5.1.1 at pertinent operational conditions based on the mission profiles of 3.2.14.

4.5.1.2.3 Jet blast deflector (JBD) acoustic and thermal measurements. (____)

Tests of carrier based airframes are required to measure the airplane acoustic and thermal environment forward and aft of the JBD. The test site shall be free of snow and water. Wind velocity shall not exceed 15 knots, ambient temperature shall not exceed 80°F, and relative humidity shall be between 40 and 80 percent. Measurements shall be accomplished at each of the following test positions and engine power settings.

a. Forward of JBD. The test airplane shall be positioned forward of the JBD in three positions simulating the most critical battery positions which would exist aboard carriers. These positions shall be between 58 feet and 68 feet as measured from catapult station zero to the JBD hinge line. At each of the three positions, all engines of the test airplane shall be stabilized at intermediate thrust for not less than the time required to attain

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equilibrium structural temperatures, followed by stabilization at maximum thrust for not less than 30 seconds.

b. Aft of JBD. The test airplane shall be positioned aft of the JBD with a second airplane in front of the JBD. The second airplane shall be selected from carrier qualified aircraft in the inventory such that the airplane/JBD combination shall impart on the test airplane the most critical environment. The test airplane shall be centered immediately behind the JBD with the test airplane centerline perpendicular to the JBD hinge line and separately with the test airplane centerline at a 45 degree angle to the JBD hinge line. For each test airplane position, all second airplane engines shall be stabilized at intermediate thrust for not less than 60 seconds, followed by stabilization at maximum thrust for not less than 30 seconds. All test airplane engines shall operate at idle power during each measurement.

4.5.2 Internal noise. (___)

Analyses and tests shall verify that the internal acoustic levels meet the requirements of 3.5.2.

4.5.2.1 Analyses.

Internal acoustic levels shall be predicted based on internal noise sources and the near field aeroacoustic predictions of 4.5.1.1 for pertinent operational flight and ground usage defined in 3.2.14.

4.5.2.2 Measurements.

Internal acoustic levels shall be measured at personnel stations for pertinent flight conditions as determined by the analyses of 4.5.2.1.

4.6 Vibration.

Analyses and tests shall verify that the airframe can operate in the vibration environments of operational use as required by 3.6.

4.6.1 Analyses.

Vibration levels shall be predicted for the airframe and components based on the sources of 3.6 and the service life and usage of 3.2.14.

4.6.2 Tests.

4.6.2.1 Development tests.

Development tests are required for structures which cannot be adequately analyzed.

4.6.2.2 Ground vibration tests.

Ground vibration tests of a complete airframe in accordance with 4.7.d(1) shall include determination of natural frequencies, mode shapes, and damping of vibration of airframe components supportive of the requirements of 3.5 and 3.6.

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4.6.2.3 Ground and flight vibration measurements.

Ground and flight vibration measurements shall be conducted to verify and correct predicted vibration levels, and demonstrate that there are no excessive vibrations. Measurements shall be made at a sufficient number of locations to define the vibration characteristics of the airframe and for flight and ground operating conditions in accordance with the service life and usage of 3.2.14.

4.7 Aeroelasticity.

Analyses and tests shall verify that the air vehicle can operate in the flight environment associated with the operational use as required by the aeroelastic stability requirements of 3.7.

a. Analyses.

(1) Basic air vehicle flutter analyses. (___)

(2) Control surface, tab, and other component flutter analyses. (___) These analyses shall be conducted for normal and failure conditions. For circuit stiffness designed control surfaces, tabs and other movable components, free play limits and maximum allowable inertial properties shall be determined and established in maintenance manuals. Techniques and procedures shall be developed for free play inspection and maintenance at field and depot levels. In addition, maintenance plans and manuals must include a process for checking and adjusting mass balance after surface repair or painting.

(3) Divergence analyses. (___)

(4) Buzz analyses. (___)

(5) Airplane with external store flutter analyses. (___) Stores shall be put into inertia and aerodynamic properties classes for the range of required store loadings such as to minimize the total airplane with external stores analyses effort. Sway brace preloads shall be defined and established in appropriate user manuals.

(6) Panel flutter analyses. (___)

(7) Whirl flutter analyses. (___)

(8) Aeroservoelastic stability analyses. (___)

b. Wind tunnel model tests.

(1) Low speed flutter model tests. (___)

(2) High speed flutter model tests. (___)

(3) Unsteady pressure measurements. (___)

c. Laboratory tests.

(1) Component ground vibration tests. (___)

(2) Mass measurements of control surfaces and tabs. (___)

(3) Control surface, tab, and actuator rigidity, free play, and wear tests. (___)

(4) Component stiffness tests. (___)

(5) Balance weight attachment verification tests. (___)

(6) Damper qualification tests. (___)

(7) Thermoelastic tests. (____)

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d. Air vehicle ground tests. Ground tests shall be performed to obtain data to validate, and revise if required, the dynamic mathematical models which are used in structural dynamic analyses, aeroelastic and aeroservoelastic stability analyses.

(1) Complete air vehicle ground vibration modal tests. (_____)These tests shall be performed on the first Engineering/Manufacturing Development (EMD) aircraft prior to its first flight and on the EMD aircraft to be used for flight flutter tests (if the first EMD aircraft is not used for this testing) prior to its first flight. These tests shall be repeated on the last EMD aircraft (_____).

(2) Aeroservoelastic ground tests of the air vehicle and its flight control augmentation systems. (___) These tests shall be performed on the first EMD aircraft prior to its first flight.

e. Air vehicle flight tests.

(1) Initial flight speed limits. An initial flight envelope shall be established to cover any planned flight testing prior to flight flutter testing. This envelope shall be limited to a maximum speed of _______ percent of V_L/M_L or _______ percent of the predicted flutter speed boundary, whichever is lower.

(2) Flight flutter tests. (___)

(3) Flight aeroservoelastic stability tests of the air vehicle and its flight control augmentation system. (___)

4.7.1 Aeroelastic stability.

The analyses and tests of 4.7 shall be of sufficient scope to verify that the airframe structure meets the aeroelastic stability requirements of 3.7.1 and subsequent subparagraphs.

a. Airspeed margin. The analyses and tests of 4.7 shall be of sufficient scope to verify that the airframe structure meets the airspeed margin requirements of 3.7.1a.

b. Damping. The analyses and tests of 4.7 shall be of sufficient scope to verify that the airframe structure meets the damping requirements of 3.7.1b.

4.7.2 Aeroservoelasticity.

The analyses and tests of 4.7 shall be of sufficient scope to verify that the airframe structure meets the aeroservoelastic stability requirements of 3.7.2.

4.7.3 Fail-safe stability.

The analyses and tests of 4.7 shall be of sufficient scope to verify that the airframe structure meets the fail-safe stability requirements of 3.7.3.

4.7.4 Free play of control surfaces and tabs.

The analyses and tests of 4.7 shall be of sufficient scope to verify that airframe components, control surfaces and tabs, and actuating systems meets the free play requirements of 3.7.4.

4.7.5 Environmental effects - aeroelasticity.

The analyses and tests of 4.7 shall be of sufficient scope to verify that the air vehicle components are in compliance with the environmental effects requirements of 3.7.5.

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4.8 Required structure survivability - nuclear. (___)

Analyses shall be performed to verify compliance of the airframe structure with the structural survivability requirements of 3.8, along with developmental tests.

a. Analyses. A vulnerability analysis shall be performed using ________________. Stress analyses and other airframe analyses shall be expanded as necessary to show compliance of the structure with the requirements of 3.8 and for use as a data base for input to the vulnerability analysis.

b. Tests. Blast tests and other appropriate nuclear weapons effects and structure response tests shall be conducted whenever the data base is insufficient to demonstrate verification of the requirements of 3.8. Development, proof, static, damage tolerance, and other airframe tests shall be used, or expanded as necessary, to support this verification and show compliance of the structure with the requirements of 3.8.

c. Combat damage repair. The results of the above analyses and tests shall be used as a basis for the combat damage repair analysis to determine and verify the contribution of structure damage repair to meeting the air vehicle post combat damage availability time requirements.

4.9 Required structure survivability--nonnuclear. (___)

Analyses shall be performed to verify compliance of the airframe structure with the structural survivability requirements of 3.9, along with developmental tests.

a. Analyses. A vulnerability analysis shall be performed using ________________. Stress analyses and other airframe analyses shall be expanded as necessary to show compliance of the structure with the requirements of 3.9 and for use as a data base for input to the vulnerability analysis.

b. Tests. Where the data base is insufficient to obtain meaningful verification results by analyses, ballistic tests and other appropriate nonnuclear weapons effects and structure response tests shall be conducted to show that the airframe structure complies with the requirements of 3.9. Development, proof, static, damage tolerance, and other airframe tests shall be used, or expanded as necessary, to support this verification and show compliance of the airframe structure with the requirements of 3.9. In addition, other tests may be required by statuatory requirements, e.g. the Live Fire Test legislation.

c. Combat damage repair. The results of the above analyses and tests shall be used as a basis for the combat damage repair analysis to determine and verify the contribution of structure damage repair to meeting the air vehicle post combat damage availability time requirements.

4.10 Strength.

Inspections, analyses, and tests shall be performed which encompass all critical airframe loading conditions to verify that:

a. Detrimental airframe structural deformations including delaminations do not occur at or below 115 percent of design limit load.

b. Rupture or collapsing failures of the airframe structure do not occur at or below ultimate loads.

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4.10.1 Material properties.

Strength related material property verification requirements are contained in 4.2.19.1.

4.10.2 Material processes.

Strength related material processing verification requirements are contained in 4.2.19.2.

4.10.3 Internal loads.

Validity of the internal loads and configurations of efficient load paths required in 3.10.3 shall be verified by inspections, analyses, and tests.

4.10.4 Stresses and strains.

Validity of stresses and strains in airframe structural members complying with the requirements of 3.10.4 shall be verified by inspections, analyses, and tests.

4.10.4.1 Fitting factor.

Fitting factors shall be shown to be in compliance with the requirements of 3.10.4.1 by analyses.

4.10.4.2 Bearing factor.

Bearing factors shall be shown to satisfy the requirements of 3.10.4.2 by analyses.

4.10.4.3 Castings.

All castings shall be shown to satisfy the casting factor requirements of 3.10.4.3 by analysis. Non-critical castings with a casting factor of 1.33 or greater require no special testing in excess of the requirements of 4.10.5.2. Critical castings, castings used in primary structure, or castings with a casting factor less than 1.33 must meet the following requirements:

a. Receive 100 percent inspection by visual and magnetic particle or penetrant or approved equivalent non-destructive inspection methods.

b. Three sample castings from different lots must be static tested and shown to meet the deformation requirements of 4.10.a. at a load of 1.15 times the limit load, and meet the ultimate strength requirements of 4.10.b. at a load of the casting factor times the ultimate load. After successful completion of these tests, a casting factor of greater than 1.00 need not be demonstrated during the full scale static test.

c. The castings must be procured to a specification that guarantees the mechanic properties of the material in the casting and provides for demonstration of these properties by test coupons cut from cut-up castings on a sampling basis and from test tabs on each casting.

d. Meeting the analytical requirements of 3.10.4.4 without a casting factor.

e. Meet the service life requirements of 3.2.14 for both crack initiation and crack growth for flaws representative of the casting and manufacturing process.

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4.10.4.4 High variability structure.

High variability structure shall be shown to satisfy the requirements of 3.10.4.4 by analyses. These analyses should be conducted using at least the following considerations in the critical combinations of these acceptable extremes:

a. Minimum thickness or area.

b. Critical dimensions such as longest column length.

c. "A" allowables for all properties including E or lowest guaranteed properties or lowest incoming inspection limits, whichever are the most critical.

d. Critical allowable tolerance buildup, eccentricities, or fit up stresses.

e. Properties that result from the edges or corners of the processing windows or processing controls.

f. Minimum edge or end fixities unless large scale test results are available for the same configuration, then minimum test derived edge or end fixities may be used.

g. Critical range of fastener flexibility.

h. Other _______________.

4.10.5 Static strength.

Laboratory load tests of instrumented airframe and major parts thereof, shall verify that the airframe structure static strength requirements of 3.10.5 are met. This instrumentation is required to validate and update the structural strength analyses. The applied test loads, including ultimate loads, shall reflect those loads resulting from operational and maintenance loading conditions.

4.10.5.1 Development tests.

The contractor shall conduct development tests as defined herein. These tests are for the purpose of establishing design concepts, providing design information, establishing design allowables, and providing early design validation. These tests are critical in reducing and managing the design risk such that the program goes into the full scale static test with a reasonable chance of success.

4.10.5.1.1 Design development tests.

Where data does not exist or is incomplete, these tests are to establish design concepts and to provide design information and early design validation. Design development tests shall include but not be limited to:

a. Element Test (Coupons/Elements). These tests are typically run with sufficient sample size to determine a statistical compensated allowable.

(1) Material selection properties including structural design allowables.

(2) Environmental effects including temperature, moisture, fuel immersion, chemicals, etc.

(3) Fastener systems, fastener allowables, and bonding evaluation.

(4) Process evaluation including all corners of the allowable processing window.

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b. Structural Configuration Development Tests (Subcomponents/Components). These tests are typically run with a smaller sample size and as such the results are used to validate the analytical procedures and establish design allowables. Actual material properties and dimensions should be used when determining correction factors, and the lower range of test results used for design allowables compatible with the statistical requirements of 3.2.19.1.

(1) Splices and joints.

(2) Panels (basic section).

(3) Panels with cutouts.

(4) Fittings.

(5) Critical structural areas which are difficult to analyze due to complexity of design.

(6) Manufacturing methods evaluation including all acceptable variations such as gaps, pulldown, shimming, etc.

(7) Composite failure modes and strain levels.

(8) Environmental effects on composite failure modes and failure strain levels.

c. Large Component Development Tests. These tests are to allow early verification of the static strength capability and producibility of final or near final structural designs of critical areas. The actual number and types of tests will depend upon considerations involving structural risk, schedule, and cost. The large component tests should be of large assemblies or full scale components such as wing carry through, horizontal tail support, wing pivots, landing gear support, complex composites, large structural castings, or any unique design features with design unknowns in:

(1) Splices and joints

(2) Fittings

(3) Panels

(4) Stability critical end or edge fixates

(5) Out of plane effects in composites

(6) Post buckled structure

(7) Environmental effects on composite failure modes and failure strain levels

d. Design Development Testing Approach for Composites. A building block approach to design development testing is essential for composite structural concepts, because of the mechanical properties variability exhibited by composite materials, the inherent sensitivity of composite structure to out of plane loads, their multiplicity of potential failures modes, and the significant environmental effects on failure mode and allowable. Special attention to development testing is required if the composite parts ultimate strength is to be certified with a room temperature/lab air static test. Sufficient development testing must be done with an appropriately sized component to validate the failure mode and failure strain levels for the critical design cases with critical temperature and end of life moisture.

4.10.5.2 Static tests - complete airframe.

Static tests, which include tests to design ultimate load, shall be performed on the complete, full scale airframe to verify its ultimate strength capability. This requirement shall be considered

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complied with, if specifically approved by the acquisition activity, on the airframe or components, thereof, for which it can be shown that:

a. The airframe and its loadings are essentially the same as that of a previous airframe which was verified by full scale tests; or

b. The strength margins, particularly for stability critical structures, have been demonstrated by major component tests; or

c. The components have been designed to the factors of uncertainty of ______, as verified by strength analysis and data, and the design allowables for critical features (such as stability critical structure, complex or new design concepts, etc.) have been demonstrated by large component tests. This method does not constitute completion of an ultimate static test in meeting the requirements of 4.10.5.3, 4.10.5.4, 4.10.5.5, 4.10.7, and 4.10.8.

4.10.5.2.1 Static testing of composites.

To establish the test demonstrated strength level, and account for the degradation of material properties due to combined temperature and moisture effects, in order of preference, one of the following methods shall be applied to the testing of composites:

a. Environmentally precondition the test article for the worst case combination of temperature-moisture condition and test under these conditions to 150 percent design limit load.

b. Test the composite article at room temperature with lab air to a load level in excess of ultimate to demonstrate the environmental knock down factors for temperature and moisture. The strains measured at 150 percent design limit load in the critical location of the composite structure must be less than the failure strains in the environmentally conditioned development tests for the same design details and loadings. Development testing must also show that there is no change in failure mode between environmental conditioned and room temperature/lab air. Development testing must also validate the statistically compensated knock down factor. It is recognized for hybrid structure (metallic and composite) that failure may occur prior to achieving the environmentally compensated load level. If the environmental knock down is greater than 10 percent, this approach requires the approval of the procuring agency.

4.10.5.2.2 Complete airframe versus separate components.

With approval by the acquisition activity, static tests may be performed on a complete airframe or on separate, major components (such as wing, fuselage, empennage, landing gear, etc.).

4.10.5.2.3 Test loadings.

The test loads shall be applied using a system capable of providing accurate load control to all points simultaneously and shall contain emergency modes which can detect load errors and prevent excessive loads. In each test condition, parts of the structure critical for the pertinent loading shall be loaded with the best available loads.

4.10.5.2.4 Simplification and combination of loading.

Simplifying loading conditions and combining the loading conditions shall be considered during the tests, provided the method and magnitude of resultant loadings do not induce unrepresentative, permanent deformations or failures. Loads resulting from pressurization shall

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be considered and, if critical, shall be simulated in combination with the applicable flight and ground loads during the appropriate component or full scale test.

4.10.5.3 Functional proof tests prior to first flight.

Prior to the first flight of the first flight article, proof tests shall be conducted to demonstrate the functioning of flight-critical structural systems, mechanisms, and components whose correct operation is necessary for safe flight. These tests shall demonstrate that the deformation requirements of 3.2.13 have been met. The functional proof tests that will be conducted, the articles on which they will be conducted, and the load level to which the systems, mechanisms, and components will be loaded are: _______________. Where these tests are not performed on every flight air vehicle, the substantiation that the planned test program is adequate to demonstrate the flight safety of all flight air vehicles is documented in ____________________.

4.10.5.4 Strength and pressurization proof tests.

Strength proof tests shall be successfully performed on every airframe or parts thereof to be operated before ultimate load static tests are successfully performed or if static tests are not performed. Pressurization proof tests shall be successfully performed on every airframe prior to pressurized flight. These proof tests shall demonstrate that the deformation requirements of 3.2.13 have been met at all load levels up to the maximum loads expected to be encountered during flight for flight anywhere within the released flight envelope including the effects of recovery from upsets and the system failures of 3.2.22. These proof tests shall also validate the accuracy of the strength predictive methods through comparisons of measured critical internal loads, strains, stresses, temperatures, and deflections with predicted values. Re-proof tests shall be conducted when flight test data indicates that actual loads or load distributions are more severe than those used in the previous proof tests. In cases where these tests are not fully representative of the actual flight environment, where the scope of the planned proof tests is not complete, or where all air vehicles normally tested will not be tested, the substantiation of the adequacy of the planned proof tests is documented in ____________________.

a. Strength proof test load levels shall be equal to _______________ percent of limit mechanical loads or the maximum mechanical loads to be encountered during flight, each multiplied by a factor of ____, whichever is less to account for overshoot, and _______________ percent of limit thermal loads or the maximum thermal loads to be encountered in flight, each multiplied by a factor of ____, whichever is less to account for overshoot. The proof load distributions shall be equal to or more severe than the predicted load distributions.

b. Prior to the first flight with pressurized compartments, each pressurized compartment of each pressurized flight air vehicle shall be pressure proof tested to _______________ percent of the maximum pressure limit loads of 3.4.1.12. Subsequent to the successful completion of ultimate pressurization tests on the static test article, each air vehicle shall be pressure proof tested to the maximum operating pressure differential attainable with normal pressure control system operation multiplied by a factor of _______________. Where necessary to demonstrate combined external load and internal pressurization strength, the pressure proof tests shall be combined with the strength proof tests of subparagraph a. above.

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4.10.5.5 Post proof test inspections and analyses.

Post proof test inspections, including nondestructive inspection (NDI), shall be conducted to determine if detrimental deformation has occurred in any structural part that would prohibit its usage on the airframe in compliance with the requirements of 3.2.14. Extensive examination of instrumentation data shall be accomplished to determine whether extrapolated, ultimate internal stresses are above predicted values to the extent that airframe structural flight restrictions or modifications are required.

4.10.5.6 Failing load tests. (___)

When ultimate load tests are completed, failing load tests shall be conducted to fail the test airframe by increasing the test loads of the most severe test loading condition.

4.10.6 Dynamic strength.

Prior to release for flight verification testing, component or total airframe laboratory testing shall be conducted to demonstrate energy absorption compliance and to validate design loads analysis. For land-based aircraft with maximum limit sink rates less than or equal to 10 feet per second (fps), system functions may be demonstrated by component landing gear jig drops which demonstrate both design conditions and the required reserve energy conditions. For shipboard aircraft, drop tests of the complete airframe shall be conducted.

4.10.7 Initial and interim strength flight releases.

a. Prior to the initial flight release, the airframe shall be satisfactorily strength analyzed for reacting all predicted limit and ultimate loads and this analysis shall be approved by the procuring activity. Also, prior to the initial flight release, the functional proof test requirements of 4.10.5.3 and 4.10.5.4 shall be successfully met if the ultimate static strength tests have not been performed. Prior to first pressurized flight of all air vehicles, the pressurization proof test requirements of 4.10.5.4 shall be successfully met.

b. Prior to flight beyond the initial strength flight release, the accuracy of the loads predictive methods shall be validated by using an instrumented and calibrated flight test air vehicle to measure actual loads and load distributions during flight within the initial strength flight release envelope. Also, prior to flight beyond the initial strength flight release, the strength proof test requirements of 4.10.5.4 shall be successfully met if the ultimate static strength tests have not been performed. Extrapolations of the measured data beyond the initial flight limits shall be used to establish the expected conservatism of the predictive methods for flight up to limit loads. This procedure of loads measurement and data extrapolation shall be used to validate the conservatism of the strength analysis and strength proof tests for each incremental increase in the strength flight release envelope up to limit loads or the strength envelope cleared through the strength proof testing of 4.10.5.4, whichever is less.

4.10.8 Final strength flight release.

For final strength flight release of the flight test article and service inventory air vehicles, the requirements of 3.10.8 shall be complied with by tests.

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4.10.9 Modifications.

To verify that the airframe with modifications has adequate structural capability for the planned usage, the analyses and tests of 4.10.5, 4.10.6, 4.10.7, and 4.10.8 shall be performed.

4.10.10 Major repairs, reworks, refurbishment, remanufacture.

The major repairs, extensive reworks, extensive refurbishment, or remanufacture of an existing air vehicle shall be documented and the airframe verified by analysis, inspections, and tests. The contractor shall review, update, and reestablish the technical database on each airframe as required to verify the airframe structural integrity and to support the intended usage and capability. Testing is required to reestablish the technical database as analysis alone is insufficient to reestablish this technical database. Proof testing of each airframe may be the option of choice.

4.11 Durability.

The durability requirements of 3.11 shall be detailed and included in the detailed structural criteria of 3.1.

4.11.1 Fatigue cracking/delamination damage.

The durability analyses and tests shall be of sufficient scope to demonstrate that the airframe structure meets the requirements of 3.11.

4.11.1.1 Analyses.

The analytical requirements of 3.11.1 can be met by either one of the following methods but the analysis method or methods selected shall be compatible with the user's life management concept. Beneficial effects of life enhancement processes must be approved by the procuring activity. The general service life requirement is specified in 3.2.14 whereas special life requirement is specified in 3.11.5.

a. Fatigue analysis with a scatter factor of _______ applied shall support two design service lives of testing without crack initiation. Specific scatter factors shall be applied such that crack initiation shall not occur in ______ analytical lives for ship-based and land-based aircraft, and corresponding back-up structure, high strength structure, and other special structures.

b. Crack growth analysis from a typical manufacturing initial quality flaw shall not grow to functional impairment in two times design service life.

c. While these analytical methods are considered equivalent to determine the design product configuration, sizing, and robustness, special situations can occur for certain material/spectrum combinations where the fatigue, crack growth, and fracture toughness characteristics are not balanced. In these special situations, the analytical method and/or flaw sizes must be approved by the procuring agency.

4.11.1.2 Tests.

The following tests shall be performed to show that the airframe structure meets the requirements of 3.11.1.

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4.11.1.2.1 Development tests.

Development tests shall be conducted to provide data for establishing design concepts, providing early analysis procedure validation, selecting materials, determining spectrum effects and validating critical component durability. Using existing data to meet this requirement shall be justified. Development tests shall include but not be limited to:

a. Element test. These tests are typically run with sufficient sample size to determine a statistical compensated allowable.

(1) Material selection properties including structural design allowables.

(2) Environmental effects including temperature, moisture, fuel immersion, chemicals, etc.

(3) Fastener systems, fastener allowables, and bonding evaluation.

(4) Process evaluation including all corners of the allowable processing window.

b. Structural configuration development tests. These tests are typically run with a smaller sample size, and as such, the results are used to validate the analytical procedures and establish design allowables. Actual material properties and dimensions should be used when determining correction factors, and the lower range of test results used for design allowables.

(1) Splices and joints.

(2) Panels (basic section).

(3) Panels with cutouts.

(4) Fittings.

(5) Critical structural areas which are difficult to analyze due to complexity of design.

(6) Manufacturing methods evaluation including all acceptable variations such as gaps, pulldown, shimming, etc.

(7) Composite failure modes and strain levels.

(8) Environmental effects on composite failure modes and failure strain levels.

c. Large component development tests. These tests are to allow early verification of the durability capability and producibility of final or near final structural designs of critical areas. The actual number and types of tests will depend upon considerations involving structural risk, schedule, and cost. The large component tests should be of large assemblies or full scale components such as wing carry through, horizontal tail support, wing pivots, landing gear support, complex composites, large structural castings, or any unique design features with design unknowns in:

(1) Splices and joints.

(2) Fittings

(3) Panels

(4) Stability critical end or edge fixates

(5) Out of plane effects in composites

(6) Post buckled structure

(7) Environmental effects on composite failure modes and failure strain levels.

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d. Design development testing approach for composites. A building block approach to design development testing is essential for composite structural concepts, because of the mechanical properties variability exhibited by composite materials, the inherent sensitivity of composite structure to out of plane loads, their multiplicity of potential failures modes, and the significant environmental effects on failure modes and allowables. Sufficient development testing must be done with an appropriately sized component to validate the failure mode and failure strain levels for the critical design cases with critical temperature and end of life moisture.

4.11.1.2.2 Durability tests.

A complete airframe or approved alternatives shall be durability tested to show that the airframe structure meets the required service life specified in 3.2.14. Critical structural areas, not previously identified by analyses or development tests, shall be identified. Any special inspection and modification requirements for the service airframe shall be derived from these tests.

a. Test article. The test airframe shall be structurally identical to the operational airframe. Any differences, including material or manufacturing process changes will be assessed for durability impact. Significant differences will require separate tests of a production article or selected component to show that the requirements of 3.11 are met for the operational airframe.

b. Test schedule.

(1) The airframe durability test shall be performed such that one lifetime of durability testing plus an inspection of critical structural areas in accordance with 4.11.1.2.2.e shall be completed in time to support ___________.

(2) Two lifetimes of durability testing plus an inspection of critical structural areas in accordance with 4.11.1.2.2.e shall be completed in time to support __________________.

c. Test evaluation. All test anomalies which occur within the duration specified in 4.11.1.2.2.f, to include areas which have initiated cracking or delamination as determined by post test teardown inspection, shall be evaluated for production and retrofit modifications, particularly with respect to those anomalies which would impose undue inspection burden for carrier based aircraft. Test anomaly analyses must be correlated to test results, and the adjusted analyses must show that the test anomalies meet the durability requirements of 3.11 and the damage tolerance requirements of 3.12 (if applicable). Modifications shall also be shown to satisfy durability and damage tolerance requirements either by test or analysis at the discretion of the acquisition activity.

d. Test spectrum. The test spectrum shall be derived from and be consistent with 3.2.14.6. and 3.11. Truncation, elimination, or substitution of load cycles is allowed subject to approval by the acquisition activity.

e. Inspections. Inspections shall be performed as an integral part of the durability tests and at the completion of testing. These inspections shall consist of design inspections, special inspections, and a post-test complete teardown inspection after test completion.

f. Duration. A minimum of two lifetimes of durability testing except as noted below is required to certify the airframe structure. A third lifetime testing shall be performed to support damage tolerance requirements, repair/modification changes, usage changes, and life extension potential.

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(1) Ship based aircraft nose landing gear and backup structure shall have _____ lifetimes of durability testing.

(2) Ship-based aircraft main landing gear and backup structure shall have _____ lifetimes of durability testing.

(3) Land based aircraft nose and main landing gear shall have _____ lifetimes of durability testing.

(4) High strength parts analyzed by fatigue analysis shall have _____ lifetimes of durability testing.

(5) Others: __________.

4.11.2 Corrosion prevention and control.

Corrosion prevention and control measures including the following elements shall be established and implemented in accordance with the following to verify that the requirements of 3.11.2 are met.

a. The criteria for the selection of corrosion resistant materials and their subsequent treatments shall be defined. The specific corrosion control and prevention measures shall be defined and established as an integral part of airframe structures design, manufacture, test and usage, and support activities.

b. Organic and inorganic coatings for all airframe structural components and parts, and their associated selection criteria shall be defined.

c. Procedures for requiring drawings to be reviewed by and signed off by materials and processes personnel shall be defined.

d. Finishes for the airframe shall be defined. General guidelines shall be included for selection of finishes in addition to identifying finishes for specific parts, such that the intended finish for any structural area is identified.

e. The organizational structure, personnel, and procedures for accomplishing these tasks shall be defined and established.

4.11.3 Thermal protection assurance.

The following tests and analyses shall be performed to verify that the thermal protection systems of the airframe meet the requirements of 3.11.3: ___________________.

4.11.4 Wear and erosion.

The following tests and evaluation shall be performed to show that the airframe structure meets the requirements of 3.11.4: _____________.

4.11.5 Special life requirement structure.

The following analyses and tests shall be performed to show that airframe meets the requirements of 3.11.5: _____________.

4.11.6 Nondestructive testing and inspection (NDT/I).

The NDT/I engineering and application efforts during design, testing, and production shall be documented.

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4.12 Damage tolerance.

Analysis and test shall be performed to verify that the airframe structure meets the damage tolerance requirements of 3.12 through 3.12.2.3. Beneficial effects of life enhancement processes must be approved by the procuring activity. The damage tolerance requirements shall be detailed and included in the structural criteria of 3.1.1.

4.12.1 Flaw sizes.

Production inspections shall be performed on 100 percent of all fracture critical regions of all airframes and related structural components. These inspections shall include, as a minimum, close visual inspections of all holes and cutouts and conventional ultrasonic, penetrant, or magnetic particle inspection of the remainder of the fracture critical region. When automatic hole preparation equipment is used, acquisition activity approved demonstration to quality and statistically monitor hole preparation and fastener installation may be established and implemented to satisfy this requirement.

a. Special nondestructive inspections.

(1) Where initial flaw assumptions for safety of flight structures are less than those of 3.12.1, a nondestructive inspection demonstration shall be performed. This demonstration shall verify that all flaws equal to or greater than the assumed flaw size will be detected with a statistical confidence of _______________.

(2) The demonstration shall be conducted on each selected inspection procedure using production conditions, equipment, and personnel. The defective hardware used in the demonstration shall contain actual flaws and cracks which simulate the case of tight fabrication flaws. Subsequent to successful completion of the demonstration, specifications on these inspection techniques shall become the manufacturing inspection requirements and may not be changed without requalification and acquisition activity approval.

b. Inspection proof tests. Component, assembly, or complete airframe inspection proof tests of every airframe shall be performed whenever the special nondestructive inspections of 4.12.1 cannot be validated and initial flaw assumptions for damage tolerant structures are less than those of 3.12.1. The purpose of this testing shall be to define maximum possible initial flaw sizes or other damage in slow crack growth structure.

c. In-service inspections. Demonstration test articles shall be inspected to show that any required in-service inspection can be conducted on the airframe. The airframe shall be inspected in accordance with the designated inspectability levels of 3.12 during the course of the testing of 4.11.1.2.2 and 4.12.2.b.

4.12.2 Residual strength and damage growth limits.

Analyses and tests shall be conducted to verify that the airframe meets the damage tolerance requirements of 3.12.

a. Analyses. Damage tolerance analyses consisting of crack growth and residual strength analyses shall be performed. The analyses shall assume the presence of flaws placed in the most unfavorable location and orientation with respect to the applied stresses and material properties. The crack growth analyses shall predict the growth behavior of these flaws in the chemical, thermal, and sustained and cyclic stress environments to which that portion of the component shall be subjected in service. The flaw sizes to be used in the analysis are those defined in 3.12.1. The flight-by-flight stress spectra and chemical and thermal environment spectra shall be developed in accordance with 4.2.15 and 3.12.2.a.

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Spectrum interaction effects, such as variable loading and environment, shall be accounted for. The analyses shall demonstrate that cracks growing from the flaw sizes of 3.12.1 will not result in sustained crack growth under the maximum steady flight and ground loads of the usage of 3.2.14 as modified by 3.2.12.a.

b. Tests, development (___) and full scale (___) damage tolerance tests are required to demonstrate that the airframe structure meets the requirements of 3.12. The material properties derived from development tests shall be consistent and congruent with those properties of the same material, in the same component, used by the other structures disciplines. See 3.2.19.1.

4.13 Durability and damage tolerance control.

The durability and damage tolerance control process shall be properly documented and implemented to ensure that maintenance and fatigue/fracture critical parts meet the requirements 3.11 and 3.12.

4.14 Sensitivity analyses.

Verification of 3.14 shall be accomplished by sensitivity analyses to evaluate the proposed structure's optimum design and to identify the performance, and cost impacts of more robust design options. The analysis shall include variation of parameters such as projected weight growth after IOC, performance and utilization severity in the selection of detailed structural configurations.

4.15 Force management.

Verification of 3.15 and subparagraphs shall be accomplished by analyses and tests to ascertain that all requirements are met.

a. Analyses. Analyses which support the force management and maintenance concepts of the procuring activity are required to verify, for each fatigue critical location, that the individual aircraft tracking (IAT) methodology is updated and well correlated to full scale durability, damage tolerance, and flight load test results.

b. Tests. Demonstration tests shall be performed to verify that the data acquisition system records and processes all required aircraft systems and flight parameters necessary for the IAT methodology.

4.16 Production facilities, capabilities, and processes.

These requirements shall be incrementally verified by examination, inspections, analyses, demonstration, and/or test. The incremental verification shall be consistent with the expectations for design maturity expected at key decision points in the program.

4.17 Engineering data requirements verification.

Data requirements content and format for studies, analyses, and test requirements shall be selected from the DOD Authorized Data List and shall be reflected in the contractor data requirements list (DD Form 1423) attached to the request for proposal, invitation for bids, and the contract as appropriate. Documentation and submittal of data and on-site review requirements shall be in accordance with and supportive of the activities identified in 4.0 and shall be subject to approval of the procuring activity. The documentation of the data shall also

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be compatible with generation and support of technical orders and maintenance plans, and allow the using command a database to support and manage the aircraft throughout its life.

5. PACKAGING.

5.1 Packaging.

For acquisition purposes, the packaging requirements shall be as specificed in the contract or order (see 6.2). When actual packaging of materiel is to be performed by DoD personnel, these personnel need to contact the responsible packaging activity to ascertain requisite packaging requirements. Packaging requirements are maintained by the Inventory Control Point's packaging activity within the Military Department or Defense Agency, or within the Military Derpartment's System Command. Packaging data retrieval is available from the managing Military Department's or Defense Agency's automated packaging files, CD-ROM products, or by contacting the responsible packaging activity.

6. NOTES.

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

6.1 Definitions.

The following definitions are applicable to this specification to enhance its understanding and application.

6.1.1 Acoustic environment.

The acoustic environment is the pattern of sound pressure levels within specified boundaries.

6.1.2 Aerial delivery.

The air shipment of cargo or personnel to a point in which the cargo is delivered by airdropping or landing of the air vehicle.

6.1.3 Aeroacoustic fatigue.

Aeroacoustic 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 flight vehicles.

6.1.4 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.

6.1.5 Aircraft.

As used herein, that subset of machines designed to travel through the air, supported principally by aerodynamic forces acting on wings, and power driven.

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6.1.6 Airdrop.

Delivery of personnel or cargo from aircraft in flight.

6.1.7 Airframe.

The structure of the air vehicle including fuselage, wing, empennage, landing gear, mechanical/structural elements of the control systems, control surfaces, radomes, antennas, engine mounts, nacelles, pylons, structural operating mechanisms, structural provisions for equipment, payload, cargo, personnel, and other components specified in 1.2.3.

6.1.8 Air transport.

Delivery of personnel or cargo from point to point in which cargo is delivered by landing of the air vehicle.

6.1.9 Air vehicle.

That particular aircraft, including all airborne systems, suspension equipment, and subsystems designed to perform a designated mission or missions.

6.1.10 Auxiliary systems.

An auxiliary system is any mechanism or structure other than the airframe, power plant, or armament which performs a function at some time during the operation of the aircraft for a period exceeding two minutes, for example, heating and ventilation; pressurization, defrost and defog; inverters; pumps; auxiliary power unit (APU); etc..

6.1.11 Buzz.

Buzz is a single-degree-of-freedom flutter that is usually evidenced by a pure rotational oscillation of a control surface or, when support rigidities 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. 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.

6.1.12 Container delivery system. (CDS).

A method of airdropping containers either in single or double row in which an aft restraint is removed and the containers exit the aircraft by gravity.

6.1.13 Damage tolerance.

The ability of the airframe to resist failure due to the presence of flaws, cracks, or other damage for a specified period of unrepaired usage.

6.1.14 Damping coefficient (g).

Damping coefficient, g, is expressed by the equation g $[\ln(A_iA_j)]/\pi N$, where $N = (j - i)$, A_i is the amplitude of the ith cycle, and A_j is the amplitude of the jth cycle.

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6.1.15 Degree of inspectability.

The degree of inspectability of safety of flight structure shall be established in accordance with the following definitions.

6.1.15.1 Depot or base level inspectable.

Structure is depot or base level inspectable if the nature and extent of damage will be detected utilizing one or more selected nondestructive inspection procedures. The inspection procedures may include NDI techniques such as penetrant, X-ray, ultrasonic, etc.. Accessibility considerations may include removal of those components designed for removal.

6.1.15.2 In-flight evident inspectable.

Structure is in-flight evident inspectable if the nature and extent of damage occurring in flight will result directly in characteristics which make the flight crew immediately and unmistakably aware that significant damage has occurred and that the mission should not be continued.

6.1.15.3 In-service non-inspectable structure.

Structure is in-service non-inspectable if either damage size or accessibility preclude detection during one or more of the above inspections.

6.1.15.4 Ground evident inspectable.

Structure is ground evident inspectable if the nature and extent of damage will be readily and unmistakably obvious to ground personnel without specifically inspecting the structure for damage.

6.1.15.5 Special visual inspectable.

Structure is special visual inspectable if the nature and extent of damage is unlikely to be overlooked by personnel conducting a detailed visual inspection of the aircraft for the purpose of finding damaged structure. The procedures may include removal of access panels and doors, and may permit simple visual aids such as mirrors and magnifying glasses. Removal of paint, sealant, etc. and use of NDI techniques such as penetrant, X-ray, etc., are not part of a special visual inspection.

6.1.15.6 Walkaround inspectable.

Structure is walkaround inspectable if the nature and extent of damage is unlikely to be overlooked by personnel conducting a visual inspection of the structure. This inspection normally shall be a visual look at the exterior of the structure from ground level without removal of access panels or doors without special inspection aids.

6.1.16 Discipline.

A technical area, for example, aeroelasticity, loads, durability, strength, etc..

6.1.17 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 aerodynamic torsional moment.

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6.1.18 Durability.

The ability of the airframe to resist cracking (including stress corrosion and hydrogen induced cracking), corrosion, thermal degradation, delamination, wear, and the effects of foreign object damage for a specified period of time.

6.1.19 Durability service life.

That operational life indicated by the results of the durability tests and as available with the incorporation of approved and committed production or retrofit changes and supporting application of the force structural maintenance plan. In general, production or retrofit changes will be incorporated to correct local design and manufacturing deficiencies disclosed by test. It will be assumed that the life of the test article has been attained with the occurrence of widespread damage which is uneconomical to repair and, if not repaired, could cause functional problems affecting operational readiness. This can generally be characterized by a rapid increase in the number of damage locations or repair costs as a function of cyclic test time.

6.1.20 Factor of uncertainty.

The ratio of the load that would cause failure of a member or structure, to the load that is imposed upon it in service. For design purposes, it is the value by which limit loads are multiplied to derive ultimate loads. The factor of uncertainty has in the past been referred to as the factor of safety.

6.1.21 Fail-safe crack arrest structure.

Crack arrest fail-safe structure is structure designed and fabricated such that unstable rapid propagation will be stopped within a continuous area of the structure prior to complete failure. Safety is assured through slow crack growth of the remaining structure and detection of the damage at subsequent inspections. Strength of the remaining undamaged structure will not be degraded below a specified level for the specified period of unrepaired service usage.

6.1.22 Flutter.

A self-excited oscillation of an aerodynamic surface and its associated structure caused by a combination of the aerodynamic, inertia, and elastic characteristics of the components involved. At speeds below the flutter speed, oscillations will be damped; at the flutter speed, oscillation will persist with constant amplitude; and at speeds above the flutter speed, oscillations will, in most cases, diverge and result in damage or destruction of the structure.

6.1.23 Critical parts.

A critical part is defined as one, the single failure of which during any operating condition could cause loss of the aircraft or one of its major components, loss of control, unintentional release of or inability to release any armament store, failure of weapon installation components, or which may cause significant injury to occupants of the aircraft or result in major economic impact on the aircraft, or a significant increase in vulnerability, or a failure to meet critical mission requirements.

6.1.23.1 Fatigue/fracture critical parts.

Fatigue/fracture critical parts are primary structural components that are designed by durability and/or damage tolerance requirements, the single failure of which could lead to the loss of the

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aircraft, aircrew, or inadvertent stores release (pylons, racks, launchers, etc.). These parts generally call for special fatigue/fracture toughness controls, quality control procedures, NDT/I practices, and analytical requirements.

6.1.23.2 Fatigue/fracture critical traceable parts.

Fatigue/fracture critical traceable parts are fatigue/fracture critical parts, the single failure of which could lead to immediate loss the the aircraft, aircrew, or inadvertent stores release (pylons, racks, launchers, etc.). These parts generally call for the fatigue/fracture critical parts requirements as well as, serialization and traceability from starting stock to tail number and reverse.

6.1.23.3 Maintenance critical parts.

Maintenance critical parts are structural components that are designed by durability requirements. The failure of the part may result in functional impairment of, or major economic impact on an aircraft or subsystem performance. The failure of the part requires costly maintenance and/or part repair or replacement, which if not performed would significantly degrade performance or operational readiness. Failure of these parts will not cause a safety of flight condition. In addition to general analytical requirements, these parts generally call for special quality control procedures and NDT/I practices.

6.1.23.4 Mission critical parts.

Mission critical parts are airframe components (including secondary structure, fairings, coatings, films, etc.) whose inflight damage or failure would result in a failure to meet critical mission requirements or a significant increase in vulnerability. These parts generally call for special design criteria, special quality control procedures, and NDT/I practices.

6.1.24 Frequency of inspection.

Frequency of inspection is defined in terms of the interval between the conduct of a particular type of inspection.

6.1.25 Hardness.

A measure of the ability of a system to withstand exposure to one or more of the effects of either nuclear or nonnuclear weapons including those weapons of a chemical and biological nature. The effective hardness for a specific effect can be expressed either quantitatively or qualitatively.

6.1.26 Initial quality.

A measure of the condition of the airframe at the completion of the manufacturing and assembly process relative to flaws, defects, or other discrepancies in the basic materials or introduced during manufacture of the airframe.

6.1.27 Load factor.

The multiplying factor by which the inertial weights of the aircraft are multiplied and subsequently combined vectorally with gravitational forces to obtain a system of external applied forces equivalent to the dynamic force system acting on the aircraft during flight and ground usage.

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6.1.28 Low altitude parachute extraction system (LAPES).

LAPES is a type of airdrop used for platform loads where the load is extracted from an aircraft flying at approximately 130 KIAS and at a ramp height no greater than 15 feet.

6.1.29 Low velocity platform airdrop.

Low velocity platform airdrop is a method of airdrop used for platform loads where the load is extracted from an aircraft by extraction parachutes at an altitude of 750 feet or more above ground level.

6.1.30 Margin of safety.

The ratio of the excess allowable stress to the calculated or applied stress. The margin of safety (M.S.) is calculated as follows:

$$M.S. = \frac{F - kf}{kf} = \frac{F}{kf} - 1$$

Where F is the allowable stress, f is the calculated or applied stress, and k is any special factor such as fitting factor or bearing factor.

6.1.31 Minimum assumed initial damage size.

The minimum assumed initial damage size is the smallest crack-like defect which shall be used as a starting point for analyzing residual strength and crack growth characteristics of the structure.

6.1.32 Minimum assumed in-service damage size.

The minimum assumed in-service damage size is the smallest damage which shall be assumed to exist in the structure after completion of an in-service inspection.

6.1.33 Minimum period of unrepaired service usage.

Minimum period of unrepaired service usage is that period of time during which the appropriate level of damage (assumed initial or in-service) is presumed to remain unrepaired and allowed to grow within the structure.

6.1.34 Multiple load path - fail-safe structure.

Multiple load path fail-safe structure is designed and fabricated in segments (with each segment consisting of one or more individual elements) whose function it is to contain localized damage and thus prevent complete loss of the structure. Safety is assured through slow crack growth in the remaining structure prior to the subsequent inspection. The strength and safety will not be degraded below a specified level for a specified period of unrepaired service usage.

6.1.34.1 Multiple load path - dependent structure.

Multiple load path structure is classified as dependent if a common source of cracking exists in adjacent load paths at one location due to the nature of the assembly or manufacturing procedures. An example of multiple load path-dependent structure is planked tension skin where individual members are spliced in the spanwise direction by common fasteners with common drilling and assembly operations.

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6.1.34.2 Multiple load path - independent structure.

Multiple load path structure is classified as independent, if by design, it is unlikely that a common source of cracking exists in more than a single load path at one location due to the nature of assembly or manufacturing procedures.

6.1.35 Nonnuclear survivability.

The capability of the system required to accomplish the designated mission in the presence of nonnuclear environments created by conventional weapons, directed energy weapons, and electronic warfare.

6.1.36 Nuclear survivability.

The capability of the system required to accomplish the designated mission in the presence of nuclear environments created by direct enemy attack or from collateral effects of a nearby friendly nuclear detonation.

6.1.37 Operational needs.

Those user requirements and capabilities needed to effectively perform the designated mission or missions.

6.1.38 Pallet.

A flat structure used to support cargo for air transport. Normally referred to as a #463L Pallet."

6.1.39 Personnel ear protection.

Personnel ear protection consists of standard issue helmet, earplugs, or earmuffs.

6.1.40 Platform.

A flat structure used to support cargo and energy dissipating material for LAPES and Low Velocity Platform Airdrop. Normally referred to as an "airdrop platform."

6.1.41 Pure tone or narrow band.

If the sound pressure level of any one-third octave band exceeds the level in the adjacent one-third octave bands by 5 dB or more, that band and associated octave band shall be considered to contain pure tone or narrow band components.

6.1.42 Reported sound pressure level.

The peak sound pressure level to be reported is the arithmetic average of the measured minimum and maximum levels provided the difference between the average and maximum is 3 dB or less. If this difference is greater than 3 dB, the level to be reported shall be obtained by subtracting 3 dB from the maximum level. The peak sound pressure level means impulsive noise (bursts) as defined in American National Standard ANSI SI 13-1971 (R1976) "Methods for the Measurement of Sound Pressure Levels."

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6.1.43 Safety of flight structure.

That structure whose failure would cause direct loss of the air vehicle or whose failure, if it remained undetected, would result in loss of the air vehicle.

6.1.44 Slow crack growth structure.

Slow crack growth structure consists of those design concepts where flaws or defects are not allowed to attain the critical size required for unstable rapid crack propagation. Safety is assured through slow crack growth for specified periods of usage depending upon the degree of inspectability. The strength of slow crack growth structure with subcritical damage present shall not be degraded below a specified limit for the period of unrepaired service usage.

6.1.45 Sound pressure levels.

The sound pressure level, in decibels, of a sound is 20 times the logarithm to the base 10 of the ratio of the pressure of this sound to the reference pressure. All sound pressure levels given in decibels in this specification are based on a pressure of 0.0002 dynes/cm^2 (2×10^{-5} newtons per square meter).

6.1.46 Special mission aircraft.

Special mission aircraft include Anti-Submarine Warfare (ASW), Aircraft Early Warning (AEW), Airborne Command and Control, Electronic Countermeasures (ECM), Presidential/VIP Transports, etc..

6.1.47 Speeds.

Speeds will be in knots based upon the international nautical mile.

6.1.47.1 Calibrated airspeed (CAS).

The calibrated airspeed is the indicated airspeed corrected for installation and instrument errors. (As a result of the sea level adiabatic compressible flow correction to the air speed instrument dial, CAS is equal to the true airspeed (TAS) in standard atmosphere at sea level.)

6.1.47.2 Equivalent airspeed (EAS).

The equivalent airspeed is the indicated air speed corrected for position error, instrument error, and for adiabatic compressible flow for the particular altitude. (EAS equals CAS at sea level in standard atmosphere.)

6.1.47.3 Indicated airspeed (IAS).

The indicated airspeed is the reading of the airspeed indicator uncorrected for instrument and installation errors, but includes the sea level standard adiabatic compressible flow correction.

6.1.47.4 True airspeed (TAS).

The true airspeed is the speed at which the airplane moves relative to the air mass surrounding it. TAS equals EAS times the square root of the sea level to altitude density ratio.

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6.1.48 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, dispensers, pods (refueling, thrust augmentation, gun electronic-counter measures, etc.), targets, cargo drop containers, and drones.

6.1.48.1 Employment.

The use of a store for the purpose and in the manner for which it was designed, such as releasing a bomb, launching a missile, firing a gun, or dispensing submunitions.

6.1.48.2 Emergency jettison.

The intentional simultaneous, or nearly simultaneous separation of all stores or suspension equipment from the aircraft in a pre-set, programmed sequence and normally in the safe condition.

6.1.48.3 Selective jettison.

The intentional separation of stores or suspension equipment, or portions thereof (such as expended rocket pods), no longer required for the performance of the mission in which the aircraft is engaged.

6.1.48.4 Suspension equipment.

All airborne devices used for carriage, suspension, employment, and jettision of stores, such as racks, adapters, launchers and pylons.

6.1.49 Structure.

Any airframe metallic or non-metallic component, element or part reacting, carrying or transmitting forces or motions required for stiffness and mechanical stability.

6.1.50 Structural integrity.

The structure strength, rigidity, damage tolerance, durability and functioning of structural parts of the airframe as affecting the safe use and cost-of-ownership of the air vehicle.

6.1.51 Structural operating mechanisms.

Those operating, articulating, and control mechanisms which transmit forces and motions during actuation and movement of structural surfaces and elements.

6.1.52 Survivability.

The capability of a system to avoid and withstand a man-made hostile environment without suffering an abortive impairment of its ability to accomplish its designated mission.

6.1.53 Turbulence parameters.

$\overline{A}$, N_o, N_y are defined as follows:

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a. $\overline{A}$ is the ratio of root-mean-square incremental load to root-mean-square gust velocity, expressed as:

$$\overline{A} = \frac{\sigma_y}{\sigma_w} = \left[\frac{\int_o^{\Omega c} |H_y|^2 \Phi_w(\Omega) d\Omega}{\int_o^{\infty} \Phi_w(\Omega) d\Omega} \right]^{1/2} \qquad \frac{\text{units}}{\text{second}}$$

b. N_o is the characteristic frequency of response (the average number of times per second that the response crosses the value zero with positive slopes) or equivalently as the radius of gyration of the load power-spectral density function about zero frequency, expressed as:

$$N_o = \frac{V}{2\pi} \frac{\sigma_y}{\sigma_w} = \frac{V}{2\pi} \left[\frac{\int_o^{\Omega c} \Omega^2 |H_y|^2 \Phi_w(\Omega) d\Omega}{\int_o^{\Omega c} |H_y|^2 \Phi_w(\Omega) d\Omega} \right]^{1/2} \qquad \frac{\text{cycles}}{\text{second}}$$

where H_y, the frequency response function, is defined over the frequency range of significance as the response (amplitude and phase angle) of the output variable y to a unit sinusoidal excitation.

c. N_y is the frequency of limit load exceedances and is expressed as:

$$N_y = \sum t N_o \left[P_1 \exp\left(\frac{-[y - y_{1g}]}{b_1 \overline{A}} \right) + P_2 \exp\left(\frac{-[y - y_{1g}]}{b_2 \overline{A}} \right) \right] \qquad \frac{\text{exceedance}}{\text{second}}$$

where:

y is the net value of load or stress.

y_{1g} is the value of load or stress in 1g level flight.

t is the fraction of total mission time in each segment.

The limit loads will be multiplied by 1.5 to establish ultimate loads.

6.1.54 Vulnerability.

The characteristics of a system which cause it to suffer a definite degradation in capability to perform the designated mission as a result of having been subjected to a certain level of effects in an unnatural (man-made) hostile environment.

6.1.55 Key process characteristics.

Key process characteristics are broken into two categories, input or control characteristics, and output characteristics. Output characteristics are those process output parameters which control the associated key product characteristics. The variation in these output characteristics characterize the process, and is the primay focus of customer process control requirements. Input characteristics are those process input parameters which control the key output characteristics of the process. Input characteristics should be of primary interest to the manufacturer, and are generally the most amenable to application of statistical process control or other variability reduction techniques.

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6.1.56 Key product characteristics.

Those measurable design details that have the greatest influence on the product meeting its requirements (form, fit, function, cost, or service life).

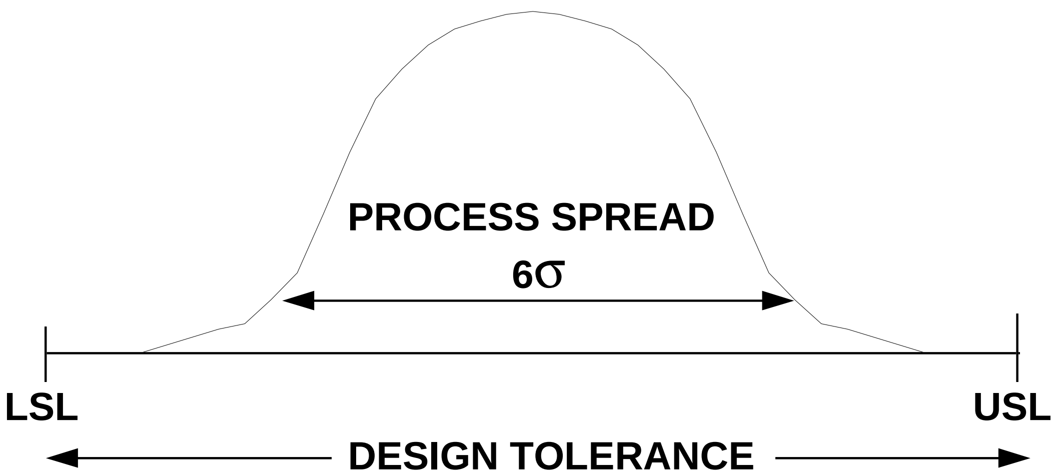
6.1.57 Key production process.

Those production processes which control key product characteristics. This may be a fabrication process, assembly process, test process, or an inspection process.

6.1.58 Process capability index (Cp).

The ratio of the design tolerance to the process variablity.

$$Cp = \frac{\text{design tolerance}}{\text{process spread}} = \frac{\text{upper spec limit - lower spec limit}}{\text{6 sigma process spread } (6\sigma)}$$



C_P

6.1.59 Process performance index (Cpk).

A comparison of the variability and centering of a controlled manufacturing process with the governing design parameter and its tolerance band. It is defined as the minimum of the following two items.

(1) process mean minus the lower specification limit, all divided by half the process spread (3 sigma), or

(2) the upper specification limit minus the process mean all divided by half the process spread (3 sigma).

$$Cpk = \frac{\text{Min[(process mean - lower spec limit), (upper spec limit - process mean)]}}{\text{1/2 process spread } (3\sigma)}$$

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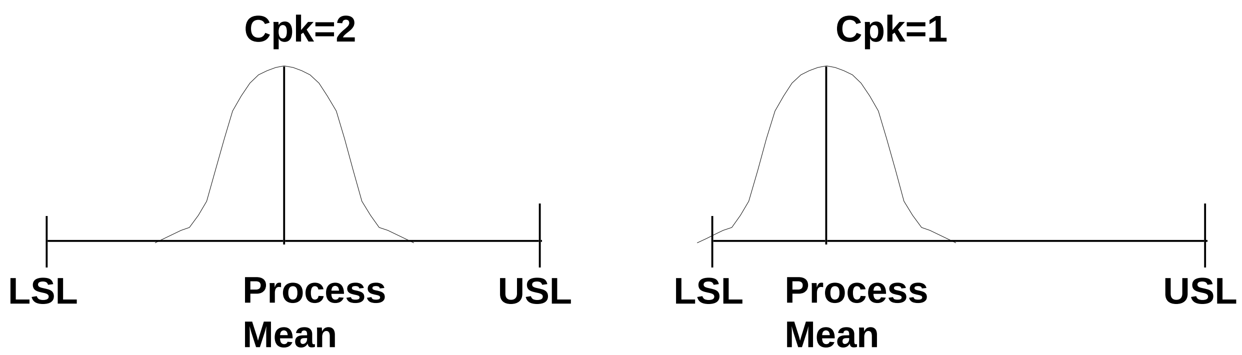

Variables data to support this may be derived form various sources. Among these are control charts created as part of formal statistical process control (SPC) procedures, data from automated or manual inspection, automated non-destructive evaluation, or computer-generated information from machines operating under adaptive controls.

6.1.60 Production.

To manufacture, fabricate, assemble, and test products according to an organized plan and with division of labor.

6.1.61 Production control.

Systematic planning, coordinating, and directing of all manufacturing activities and influences to insure having goods made on time, of adequate quality, and at reasonable cost.

6.1.62 Production process.

The basic methods required to manufacture, fabricate, assemble, and test hardware, including sub-assemblies, assemblies, components, subsystems, and systems, the associated process control technologies, and the quality assurance requirements implementation.

6.2 Acquisition requirements.

Acquisition documents must specify the following:

a. Title, number, and date of the specification.

b. Issue of DoDISS to be cited in the solicitations, and if required, the specific issue of individual documents referenced (see 2.2.1, 2.2.2, and 2.3).

c. Packaging requirements (see 5.1).

6.3 Subject term (key word) listing

Aeroacoustic

Aeroelasticity

Aeroservoelasticity

Airframe

Buffet

Carrier suitability

Corrosion

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Criteria

Critical parts

Damage tolerance

Development test

Durability

Factor of uncertainty

Fasteners

Flaws

Foreign object damage

Loads

Margin of safety

Material

Nondestructive testing and inspection

Nuclear

Residual strength

Scatter factor

Service life

Spectrum

Static test

Strength

Stress

Survivability

Thermal

Vibration

Vibroacoustic

6.4 International interest.

Certain provisions of this document are the subject of international standardization agreements (STANAG 3469TN, 3278ASP, 3098ASP, 3212ASP, 3681PHE, and 3447ASP). When change notice, revision, or cancellation of this document is proposed that will modify the international agreement concerned, the preparing activity will take appropriate action through international standardization channels, including departmental standardization offices, to change the agreement or make other appropriate accommodations.

6.5 Responsible engineering office.

The office responsible for development and technical maintenance of this specification is ASC/ENFS, Wright-Patterson AFB OH 45433-7809. Requests for additional information or technical assistance on this specification can be obtained from either ASC/ENFS, Wright-

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Patterson AFB OH 45433-7809; DSN 785-3330, Commercial (937) 255-3330; or Naval Air Systems Command/4.3.3, Arlington, VA 22243-5120, DSN 664-3400, Commercial (703) 604-3400. Any information obtained relating to Government contracts must be obtained through contracting officers.

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JOINT SERVICE SPECIFICATION GUIDE

AIRCRAFT STRUCTURES

HANDBOOK FOR

A.1 SCOPE.

A.1.1 Scope.

This appendix is a reference document which provides rationale, guidance, lessons learned, and instructions necessary to tailor sections 3 and 4 of the basic specification (JSSG-2006) for a specific application. This Appendix itself is not for contract compliance.

A.1.2 Purpose.

This appendix provides information to assist the Government acquisition activity in the use of JSGS-2006, referred to hereinafter as the specification.

A.1.3 Use.

This appendix is intended to be used in preparing contract specifications, Type I, Aircraft Structures. Supplemental information for, and completion of the blanks of the specification is to be accomplished based on operational needs, configuration interfaces and constraints, and information contained herein.

A.1.4 Format.

A.1.4.1 Requirement/verification identity.

Section 30 of this appendix parallels sections 3 and 4 of the specification and paragraph numbers and titles are in the same sequence. Section 30 restates each requirement and associated verification of the specification and provides rationale, guidance, and lessons learned applicable to each.

A.1.4.2 Requirement/verification package.

Section 30 has been arranged so the requirement and associated verification is an identifiable package to permit addition to, or deletion from the resulting tailored specification. A requirement is not specified without an associated verification.

A.1.5 Guidance.

The content of Section 1.2, Application, and Section 2, Applicable Documents, of the specification shall be tailored in accordance with the following guidance.

1.2 Application.
1.2.1 Program.
This specification applies to __________.

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REQUIREMENT RATIONALE (1.2.1)

This paragraph identifies the program, primary management responsibility, structural engineering responsibility, and level of structural engineering change required.

REQUIREMENT GUIDANCE (1.2.1)

Identify the weapon system program. Identify the agency or agencies primarily responsible for the program, and the organization(s) responsible for structural engineering. If structural modifications are involved, identify the level of structural change.

REQUIREMENT LESSONS LEARNED (1.2.1)

Programs involving significant structural modifications have been confused with programs involving minor changes. This resulted in delay and added expense when it became clear that structural changed required engineering review and evaluation before flight clearances could be validated. Care should be exercised to assure that all modification and change programs are properly identified and controlled by competent authority.

1.2.2 Aircraft.
This specification applies to ___________.

REQUIREMENT RATIONALE (1.2.2)

This paragraph is needed to identify the type of aircraft, in general descriptive terms, to which the specification applies.

REQUIREMENT GUIDANCE (1.2.2)

Describe briefly the type of aircraft. The specification applies to power driven aircraft only; however, the aircraft may be manned or unmanned, possess fixed or adjustable fixed wings, and V/STOL with similar structural characteristics of those above. For example: "This specification applies to a manned, power-driven aircraft with fixed wings." Further, the following statement or parts thereof should be included to identify those sub-systems to which the specification is not applicable: "Propulsion systems, engines, power generators, avionics, helicopters, and helicopter-type power transmission systems, including lifting and control rotors, and other dynamic machinery are not covered by this specification."

REQUIREMENT LESSONS LEARNED (1.2.2)

1.2.3 Aircraft structure.
This specification applies to metallic and nonmetallic air vehicle structures. The air vehicle structure, hereinafter referred to as the airframe, includes the fuselage, wing, empennage, landing gear, structural elements of the control systems, control surfaces, radomes, antennas, engine mounts, nacelles, pylons, in-flight refueling mechanism, carrier related apparatus/devices, structural operating mechanisms and structural provisions for equipment, payload, cargo (if applicable), personnel, and _______________.

REQUIREMENT RATIONALE (1.2.3)

This paragraph is needed to identify and define the parts and components of the air vehicle structure (airframe) to which the specification is applicable.

REQUIREMENT GUIDANCE (1.2.3)

Include in the list of airframe items, those assemblies or components which are applicable to the particular air vehicle being acquired. For example, permanently installed external fuel tanks and chemical tanks, peculiar radomes and pods, and add-on skis.

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A.1.6 Responsible Engineering Office.

The responsible engineering office (REO) for this appendix is ASC/ENFS, Wright-Patterson AFB OH 45433-7101. Requests for additional information or technical assistance with the appendix can be obtained from either ASC/ENFS, Wright-Patterson AFB. OH 45433-7101, DSN 785-3330, Commercial (937) 255-3330: or Naval Air Systems Command/4.3.3, Arlington, VA 22243-5120, DSN 664-3400, Commercial (703) 604-3400. Any information obtained relating to Government contracts must be obtained through contracting officers.

A.2 REFERENCE DOCUMENTS

A.2.1 General.

A.2.2 Government documents.

Unless otherwise indicated, the documents specified herein are referenced solely to provide supplemental technical data. These documents are for informational purposes only. Copies of the documents are not available from and will not be furnished by the Air Force.

A.2.2.1 Specifications, standards, and handbooks.

SPECIFICATIONS
Federal

QQ-A-200	Aluminum Alloy, Bar, Rod, Shapes, Structural Shapes, Tube and Wire, Extruded; General Specification for
QQ-A-367	Aluminum Alloy Forgings
QQ-C-390	Copper Alloy Castings (Including Cast Bar)
QQ-P-35	Passivation Treatments for Corrosion Resistant Steel

Department of Defense

MIL-S-5002	Surface Treatments and Inorganic Coatings for Metal Surfaces of Weapons Systems
MIL-B-5087	Bonding, Electrical, and Lightning Protection, for Aerospace Systems
MIL-G-5485	Glass, Laminated, Flat, Bullet-Resistant
MIL-S-5705	Structural Criteria, Piloted Airplane, Fuselage, Booms, Engine Mounts and Nacelles
MIL-C-6021	Castings, Classification and Inspection of
MIL-E-6051	Electromagnetic Compatibility Requirements, System
MIL-I-6088	Heat Treatment of Aluminum Alloys
MIL-W-6858	Welding, Resistance: Spot and Seam
MIL-I-6870	Inspection Program Requirements, Nondestructive for Aircraft and Missile Materials and Parts
MIL-W-6873	Welding; Flash, Carbon and Alloy Steel
MIL-H-6875	Heat Treatment of Steel, Process for
MIL-P-7034	Pulleys, Groove, Antifriction Bearing Grease Lubricated, Aircraft
MIL-F-7179	Finishes, Coatings, and Sealants for the Protection of Aerospace Weapons Systems
MIL-F-7190	Forging, Steel, for Aircraft/Aerospace Equipment and Special

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	Ordnance Applications
MIL-F-7575	Resin, Polyester, Low Pressure Laminating
MIL-S-7742	Screw Threads, Standard, Optimum Selected Series: General Specification for
MIL-B-7883	Brazing of Steels, Copper, Copper Alloys, Nickel Alloys, Aluminum and Aluminum Alloys
MIL-S-8516	Sealing Compound, Polysulfide Rubber, Electric Connectors and Electric Systems, Chemically Cured
MIL-D-8708	Demonstration: Aircraft Weapon Systems, General Specification for
MIL-S-8784	Sealing Compound, Low Adhesion, for Removable Panels and Fuel Tank Inspection Plates
MIL-S-8802	Sealing Compound, Temperature-Resistant, Integral Fuel Tanks and Fuel Cell Cavities, High Adhesion
MIL-A-8860	
MIL-A-008861	Airplane Strength and Rigidity, Flight Loads
MIL-A-008862	Airplane Strength and Rigidity-Landplane Landing and Ground Handling Loads
MIL-A-8862	Airplane Strength and Rigidity-Landplane Landing and Ground Handling Loads
MIL-A-008863	Airplane Strength and Rigidity, Ground Loads for Navy Procured Airplanes
MIL-A-8863	Airplane Strength and Rigidity, Ground Loads for Navy Acquired Airplanes
MIL-A-008865	Airplane Strength and Rigidity, Miscellaneous Loads
MIL-A-8866	Airplane Strength and Rigidity, Reliability Requirements, Repeated Loads, Fatigue and Damage Tolerance
MIL-A-008870	Airplane Strength and Rigidity, Vibration, Flutter, and Divergence
MIL-A-8870	Airplane Strength and Rigidity, Vibration, Flutter, and Divergence
MIL-A-8871	Airplane Strength and Rigidity, Flight and Ground Operations Tests
MIL-S-8879	Screw Threads, Controlled Radius Root with Increased Minor Diameter, General Specification for
MIL-A-8892	Airplane Strength and Rigidity, Vibration
MIL-A-8893	Airplane Strength and Rigidity, Sonic Fatigue
MIL-T-9046	Titanium and Titanium Alloy, Sheet, Strip, and Plate
MIL-T-9047	Titanium and Titanium Bars (Rolled or Gorged) and Reforging Stock, Aircraft Quality
MIL-R-9299	Resin, Phenolic, Laminating
MIL-R-9300	Resin, Epoxy, Low-Pressure Laminating
MIL-P-9400	Plastic Laminate and Sandwich Construction Parts and Assembly, Aircraft Structural, Process Specification Requirements
MIL-F-9490	Flight Control Systems - Design, Installation and Test of Piloted Aircraft, General Specification for
MIL-A-21180	Aluminum-Alloy Castings, High Strength
MIL-L-22589	Launching System, Nose Gear Type, Aircraft
MIL-A-22771	Aluminum Alloy Forgings, Heat Treated
MIL-S-23586	Sealing Compound, Electrical, Silicone Rubber, Accelerator Required
MIL-M-24041	Molding and Potting Compound, Chemically Cured, Polyurethane
MIL-A-25047	Markings and Exterior Finish Colors for Airplanes, Airplane Parts, and Missiles (Ballistic Missiles Excluded)
MIL-W-25140	Weight and Balance Control System (for Aircraft and Rotorcraft)

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MIL-P-25690	Plastic, Sheets and Formed Parts, Modified Acrylic Base, Monolithic, Crack Propagation Resistant
MIL-G-25871	Glass, Laminated, Aircraft Glazing
MIL-S-29574	Sealing Compound, Polythioether, for Aircraft Structures, Fuel and High Temperature Resistant, Fast Curing at Ambient and Low Temperatures
MIL-T-29586	Thermosetting Polymer Matrix, Unidirectional Carbon Fiber Reinforced Prepreg Tape (Widths up to 60 inches), General Specification for
MIL-M-38795	Manual, Technical: System Peculiar Corrosion Control, Preparation of
MIL-S-46052	Steel Castings, High Strength, Low Alloy
MIL-S-46059	Steel, Carbon and Alloy, Extruded Shapes
MIL-M-46062	Magnesium Alloy Castings, High Strength
MIL-A-46146	Adhesives-Sealants, Silicone, RTV, Noncorrosive (for Use with Sensitive Metals and Equipment)
MIL-T-81259	Tie-Downs, Airframe Design, Requirements for
MIL-G-81322	Grease, Aircraft, General Purpose, Wide Temperature Range
MIL-I-81550	Insulating Compound, Electrical, Embedding, Reversion Resistant Silicone
MIL-T-81556	Titanium and Titanium Alloys, Extruded Bars and Shapes, Aircraft Quality
MIL-S-81733	Sealing and Coating Compound, Corrosion Inhibitive
MIL-H-81200	Heat Treatment of Titanium and Titanium Alloys
MIL-F-83142	Forging, Titanium Alloys, Premium Quality
MIL-H-83282	Hydraulic Fluid, Fire Resistant, Synthetic Hydrocarbon Base, Aircraft, Metric, NATO Code Number H-537
MIL-T-83399	Test for Removal of Flux Residues
MIL-S-83430	Sealing Compound, Integral Fuel Tanks and Fuel Cell Cavities, Intermittent Use to 360 Deg F (182 Deg C)
MIL-A-83444	Airplane Damage Tolerance Requirements
MIL-W-87161	Wire Strand, Nonflexible, for Aircraft Control
MS-33522	Rivets Blind, Structural, Mechanically Locked and Friction Retainer Spindle, (Reliability and Maintainability) Design and Construction

STANDARDS

Department of Defense

MIL-STD-210	Climatic Information to Determine Design and Test Requirements for Military Systems and Equipment
MIL-STD-295	Bill of Material Preparation of
MIL-STD-810	Environmental Test Methods and Engineering Guidelines
MIL-STD-838	Lubrication of Military Aircraft
MIL-STD-866	Grinding of Chrome Plated Steel and Steel Parts Heat Treated to 180,000 psi or over
MIL-STD-889	Dissimilar Metals
MIL-STD-1374	Weight and Balance Data Reporting Forms for Aircraft (Including Rotorcraft)
MIL-STD-1515	Fastener Systems for Aerospace Applications
MIL-STD-1530	Aircraft Structural Integrity Program, Airplane Requirements
MIL-STD-1568	Materials and Processes for Corrosion Prevention and Control in

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	Aerospace Weapons Systems
MIL-STD-1587	Materials and Processes Requirements for Air Force Weapon Systems
MIL-STD-1595	Qualification of Aircraft, Missile and Aerospace Fusion Welders
MIL-STD-1599	Bearings, Control System Components, and Associated Hardware Used in the Design and Construction of Aerospace Mechanical Systems and Subsystems
MIL-STD-1757	Lightning Qualification Test Techniques for Aerospace Vehicles and Hardware
MIL-STD-1795	Lightning Protection of Aerospace Vehicles and Hardware
MIL-STD-2000	Standard Requirements for Soldered Electrical and Electronic Assemblies
MIL-STD-2175	Castings, Classification and Inspection of
MIL-STD-2219	Fusion Welding for Aerospace Applications
MIL-STD-5400	Electronic Equipment, Airborne, General Requirements for
MIL-STD-45662	Calibration Systems Requirements

HANDBOOKS

Department of Defense

MIL-HDBK-5	Metallic Materials and Elements for Aerospace Vehicle Structures
MIL-HDBK-17	Plastics for Aerospace Vehicles
MIL-HDBK-23	Structural Sandwich Composites
MIL-HDBK-275	Guide for Selection of Lubricant Fluids and Compounds for Use In Flight Vehicles and Components
MIL-HDBK-1530	Aircraft Structural Integrity Program General Guidelines For

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

Air Force Systems Command

AFSC-DH-1-2	General Design Factors
AFSC-DH-1-7	Aerospace Material
AFSC-DH-2-1	Airframe

(Copies of AFSC Design Handbooks are available from ASC/ENSI, 2530 Loop Rd W, Wright-Patterson AFB OH 45433-7101)

Other Government documents

USAF Spec No R-1803-5	Fuselage, Hull, Nacelles, and Tail Booms
SD-24	General Specifications for Design Construction of Aircraft Weapons for United States Navy

(Copies of the above documents are available from the Standardization Document Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia PA 19111-5094)

Department of Transportation

FAA-ADS-53	Development of a Power-Spectral Gust Design Procedure for Civil Aircraft
FAA-ADS-54	Contributions to the Development of a Power-Spectral Gust Design

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	Procedure for Civil Aircraft
FAR Part 25	Airworthiness Standards, Transport Category Airplanes

(Application for copies should be addressed to Department of Transportation, FAA Aeronautical Center, AML-611, P O Box 25082, Oklahoma City OK 73125-5082)

National Aeronautical and Space Administration

NACA Report 1172	Study of the Application of Power-Spectral Methods of Generalized Harmonic Analysis of Gust Loads on Airplanes
NACA Report 1272	A Re-Evaluation of Data on Atmospheric Turbulence and Airplane Gust Loads for Application in Spectral Calculations
NACA Report 1285	Summary of Derived Gust Velocities Obtained from Measurements within Thunderstorms
NASA RM-56I12	A Survey and Evaluation of Flutter Research and Engineering
NACA TN 1140	Measurements of Landing-Gear Forces and Horizontal-Tail Loads in Landing Tests of a Large Bomber-Type Airplane
NACA TN 1178	Calibration of Strain-Gage Installation in Aircraft Structures for the Measurements of Flight Loads
NACA TN 1680	Divergence of Swept Wings
NASA TN 3541	A Method of Obtaining Statistical Data on Airplane Vertical Velocity at Ground Contact from Measurements of Center-of-Gravity Accelerations
NASA-SP-415	Conference on Flutter Testing Techniques
NASA-TM-87753	Transonic Flutter Model Study of a Multijet Airplane Wing with Winglets Including Considerations of Separated Flow and Aeroelastic Deformation Effects, Nov 1986
NASA-TN-D-527	An Investigation of Landing-Contact Conditions for a Large Turbjojet Transport During Routine Daylight Operations
NASA Contractor Report 144887	Analyses and Tests of the B-1 Aircraft Structural Mode Control System
NASA Contractor Report 159097	Accelerated Development and Flight Evaluation of Active Controls Concepts Development and Flight Tests

(Application for copies should be addressed to National Technical Information Service (NTIS), 5825 Port Royal Road, Springfield VA 22161)

Test Reports

AFCRL-TR-74-0052	Synopsis of Background Material
AFFDL-TR-3060	A Method For Assessing the Impact of Wake Vortices on USAF Operations
AFFDL-TR-64-170	Design of a Low Altitude Turbulence Model for Estimating Gust Loads on Aircraft
AFFDL-TR-66-35	Application of a Power Spectral Gust Design Procedure to Bomber Aircraft
AFFDL-TR-67-13	Atmospheric Turbulence Spectra from B-52 Flight Loads Data
AFFDL-TR-67-74	Gust Design Procedures Based on Power Spectral Techniques
AFFDL-TR-67-140	Design Criteria for the Prediction and Prevention of Panel Flutter
AFFDL-TR-68-23	Takeoff and Landing Critical Atmospheric Turbulence (TOLCAT) Analytical Investigation
AFFDL-TR-68-96	V/STOL Landing Impact Criteria
AFFDL-TR-68-105	Aircraft Structural Vulnerability to Conventional Weapons
AFFDL-TR-69-11	A Procedure for Computing Power Spectral Density Data
AFFDL-TR-70-101	High Altitude Gust Criteria for Aircraft Design

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AFFDL-TR-70-106	Design Manual for Vertical Gusts Based on Power Spectral Techniques
AFFDL-TR-70-116	An Aircraft Structural Combat Damage Model Design Handbook
AFFDL-TR-71-155	Takeoff and Landing Analysis (TOLA) Computer Program
AFFDL-TR-72-46	Buffet Dynamic Loads During Transonic Maneuvers
AFFDL-TR-72-116	Active Flutter Suppression for Military Aircraft, A Feasibility Study
AFFDL-TR-73-103	Windshield Bird Strike Structural Design Criteria
AFFDL-TR-73-118	Validation of New Gust Design Procedures for Military Transports
AFFDL-TR-47-50	Survivable Combat Aircraft Structures Design Guidelines and Criteria Design Handbook
AFFDL-TR-74-67	Preliminary Design of Active Wing/Store Flutter Suppression Systems for Military Aircraft
AFFDL-TR-75-73	Effects of Internal Blast on Combat Aircraft Structures, Vol II, Effects of Detonations of High Explosive Projectiles on Fracture of Metallic Aircraft Compartments
AFFDL-TR-76-23	Preliminary Airframes Structural Design Load Prediction Techniques for Military Aircraft, Vols I - VII
AFFDL-TR-76-110	Ground Vibration Testing of Fighter Aircraft with Active Control System
AFFDL-TR-78-8	Factor of Safety USAF Design Practice
AFFDL-TR-78-29	Fiber Composite Blast Response Computer Program (BR-1FC) BR-1 Code Modification and Test Program
AFFDL-TR-78-65	Demonstration of Active Wing/Store Flutter Suppression System
AFFDL-TR-78-113	Feasibility Study for F-16 Flutter Suppression System
AFFDL-TR-78-183	Force Management Methods, Task I Report, Current Methods
AFFDL-TR-78-194	Transonic Wind Tunnel Test on an Oscillating Wing with External Stores
AFWAL-TR-3019	Comparison Tests of Integral Fuel Tank Sealing Concepts
AFWAL-TR-80-3036	Flexible Airframe Design Loads - Flexloads Update for Wing/Body Blending and Lifting Body Concepts, Volts I - III
AFWAL-TR-80-3056	An Improved Ground Vibration Test Method
AFWAL-TR-80-3059	Predicted and Measured Divergence Speeds of an Advanced Composite Forward Swept Wing Model
AFWAL-TR-80-3073	Structural Design and Wind Tunnel Testing of a Forward Swept Fighter Wing
AFWAL-TR-80-3093	Additional Demonstration of Active Wing/Store Flutter Suppression System
AFWAL-TR-80-3100	Integral Fuel Tank Test Criteria and Methods
AFWAL-TR-81-3079	Force Management Methods Handbook
AFWAL-TR-82-3040	Development and Flight Test of an Active Flutter Suppression System for the F-4F with Stores, Parts I - III
AFWAL-TR-82-3044	Test Demonstration of Digital Adaptive Control of Wing/Store Flutter, Parts I and II
AFWAL-TR-83-3039	Unsteady Transonic Pressure Measurements on a Semispan Wind Tunnel Model of a Transport Type Supercritical Wing (LANN Model)
AFWAL-TR-83-3046	Wind Tunnel Demonstration of Active Flutter Suppression on the F-16 Model with Stores
AFWAL/FIBG 81-2	AFWAL Test Report
A.R.C. TR C.P. No. 282	A Flight Investigation of the Wake Behind a Meteor Aircraft with Some Theoretical Analysis
ASD-TDR-62-555	A Rational Method for Predicting a Lighting Gear Dynamic Leads, Vol I
ASD-TDR-63-318	Development of a Low Altitude Turbulence Model for Estimating Gust

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	Loads on Aircraft
ASD-TR-72-113	Development of a Rolling Maneuver Spectrum from Statistical Flight Loads Data
ASD-TR-79-5037	Development of a Normalized Probability Distribution for Lateral Load Factors due to Aircraft Ground Turning
ASD-TR-80-5038	Comparison of Flight Load Measurements Obtained from Calibrated Strain Gages and Pressure Transducers
ASD-TR-82-5012	Handbook of Military Aircraft Design Normal Load Factor Exceedance Data
FTC-TR-73-32	Air Force Evaluation of the Fly-by-Wire Portion of the Survivable Flight Control System Advanced Development Program
FTD-MT-64-269	Aircraft In-Flight Heating
RDT-TDR-63-4139	Design Criteria for Ground-Induced Dynamic Leads, Vol I
RDT-TDR-63-4197	Proceedings of Symposium on Aeroelastic and Dynamic Modeling Technology
SEG-TR-65-4	Environmental Conditions to be Considered in the Structural Design of Aircraft Required to Operate at Low Levels
SEG-TR-66-45	A Summary of Some Recent Developments in the Description of Atmospheric Turbulence Used for Aircraft Structural Design
SEG-TR-67-2	Investigation of an ECM Rod Installation for the Model F-4C Aircraft
SEG-TR-67-28	Development of Improved Gust Load Criteria for United States Air Force Aircraft
WADC-TM-58-4	Detailed Requirements for Structural Fatigue Certification Programs
WADD-TR-60-305	B-66B Low Level Gust Study, Vol I
WADC-TR-58-31	Subsonic Flutter Model Tests of a Low Aspect Ratio Unswept All-Moveable Tail
WL-TR-94-3017	Overview of Unsteady Transonic Wind Tunnel Test on a Semispan Straked Delta Wing Oscillating in Pitch
WL-TR-94-3094 through WL-TR-94-3096	Unsteady Transonic Wind Tunnel Test on a Semispan Straked Delta Wing Oscillating in Pitch

(Application for copies should be addressed to National Technical Information Service (NTIS), 5825 Port Royal Road, Springfield VA 22161)

A.2.3 Non-Government Publications.

AIAA Paper 75-823	YF-16 Active-Control-System/Structural Dynamics Interaction Instability
AIAA Paper 75-824	Interaction Between Control Augmentation System and Airframe Dynamics on the YF-17
AIAA Paper 78-505	The Use of Transient Testing Techniques on the Boeing YC-14 Flutter Clearance Program
AIAA Paper 80-0768	F-16 Flutter Suppression System Investigation
AIAA Paper 80-0796	A Wind Tunnel Demonstration on the Principle of Aeroelastic Tailoring Applied to Forward Swept Wings
AIAA Paper 81-0591-CP	Historical Development of Flutter
AIAA Paper 81-0606	Evaluation of Methods for Prediction and Prevention of Wing/Store Flutter
AIAA Paper 82-0683	Rigid Body Structural Mode Coupling on a Forward Swept Wing Aircraft

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AIAA Paper 83-1028	Wind Tunnel Correlation Study of Aerodynamic Modeling for F1A-18 Wing-Store Tip-Missile Flutter
AIAA Paper 85-0739	Self-Induced Oscillation Wind Tunnel Test of a Variable Sweep Wing
ANC-2	Ground Loads
AGARD Advisory Rpt 1	A Survey of Panel Flutter
AGARD-AG-160	Strain Gauge Measurements on Aircraft, Vol 7
AGARD-CP-507	Conference Proceedings on Transonic Unsteady Aerodynamics and Aeroelasticity
AGARDograph 160	Aeroelastic Flight Test Techniques and Instrumentation
AGARD Report 113	Strain Gage Calibrations and Flight Loads Testing Techniques
AGARD Report 586	A Summary of Atmospheric Turbulence Recorded by NATO Aircraft
AGARD Report 596	Recent Developments in Flight Flutter Testing in the United States
AGARD Report 668	Considerations on Wing Stores Flutter, Asymmetry, Flutter Suppression
AMS 4890	Copper-Beryllium Alloy Castings 97CU - 2.1BE - 0.52CO - 0.28SI Solution Heat Treated (TB00) (UNS C82500)
AMS 5343	Castings, Investment Corrosion Resistant 16CR - 4.0NI - 3.1CU, Solution and Precipitation Heat Treated, 150,000 Psi (1034 Mpa) Tensile Strength
AMS 5355	Steel, Corrosion Resistant, Investment Castings 16Cr-4.1Ni-0.28Cb-3.2Cu Homogenization and Solution Heat Treated
AMS 5581	Nickel Alloy, Corrosion and Heat Resistant, Seamless or Welded Tubing 62Ni-21.5Cr-9.0Mo-3.7Cb Annealed
AMS 5599	Nickel Alloy, Corrosion and Hear Resistant, Sheet, Strip, and Plate 62Ni-21.5Cr-9.0Mo-3.7 (Cb+Ta) Annealed (UNS N06625)
ANSI B46.1-1978	Surface Texture (Surface Roughness, Waviness, and Lay)
ARTC-32	Panel Flutter Survey and Design Criteria
ASTM B150	Standard Specifications for Aluminum Bronze Rod, Bar, and Shapes
ASTM B 169	Standard Specifications for Aluminum Bronze Sheet, Strip, and Rolled Bar
ASTM B 194	Standard Specification for Copper-Beryllium Alloy Plate, Sheet, Strip, and Rolled Bar
ASTM B 196	Standard Specification for Copper-Beryllium Alloy Rod and Bar
ASTM B 197	Standard Specification for Copper-Beryllium Alloy Wire
ASTM E390	Standard Reference Radiographs for Steel Fusion Welds
ASTM G85.A4	Standard Practice for Modified Salt Spray (Fog) Testing
ASTM STP 866	Developing an Accelerated Test: Problems and Pitfalls
JTCG/AS-75-V-008	Required Minimum Elements of Vulnerability Assessment
NAS 411	Hazardous Materials Management Program
NASI-15080 Task 16	Divergence Suppression of Forward Swept Wings
NLR TR 77090U	Investigations of the Transonic Flow Around Oscillating Airfoils

(Application for copies of AIAA documents are available from National Headquarters, 1801 Alexander Graham Bell, Suite 500, Reston VA 22090; ANC documents are available from the Standardization Document Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia PA 19111-5094; AGARD documents are available from NASA Center for AeroSpace Information (CASI), 7121 Standard Drive, Hanover MD 21076-1320; AMS documents are available from the Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale PA 15096; ANSI documents are available from America National Standards Institute, 11 West 42nd Street,

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New York NY 10036; ASTM documents are available from American Society for Testing and Materials, 1916 Race Street, Philadelphia PA 19103; JTCG documents are available from OC-ALC/TILUB, Attn: JTCG/ME Publications Manager, 7851 Arnold Street, Suite 204, Tinker AFB OK 73145-9160; NAS, NASI, and NLR documents are available from National Technical Information Service, 5285 Port Royal Rd, Springfield VA 22161)

Advanced Composite Design Guide, Wright-Patterson AFB: Air Force Materials Laboratory.

Structural Testing for Aircraft Development, Wright-Patterson AFB: ASD/AFSC/USAF, 31 October 1968.

Garrick, I.E. and W. H. Reed, III, “Historical Development of Aircraft Flutter.” Journal of Aircraft, Vol 18, No 11 (November 1981), 897 - 912.

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Weisshaar, T. A., T. A. Zeiller, T. J. Hertz, and M. H. Shirk, Flutter of Forward Swept Wings, Analyses, and Tests, New Orleans, L: AIAA 23rd Structures, Structural Dynamics and Materials Conference, May 1982.

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A.3.0 REQUIREMENTS AND VERIFICATIONS

A.3 Requirements.

(The instructional handbook, which is contained in the appendix herein, provides the rationale for specified requirements, guidance for inclusion of supplemental information, a lessons learned repository, and ___________. This specification is meant to be tailored by filling in the blank elements according to the particular air vehicle's performance requirements and characteristics, with appropriate supporting engineering justification. In the absence of such justification and acceptance, the recommendations in the handbook shall be used to fill in the blanks of this specification. In addition, specific paragraphs may be tailored by deletion of not applicable, by inserting "N/A" in parenthesis following the number and title, or by rewriting of the paragraph by inserting "REWRITE" in parenthesis following the number and title.)

REQUIREMENT RATIONALE (A.3)

Written aircraft structures requirements are needed to define the minimum structural performance acceptable to the government and the obligations of the aircraft developer in mutually agreed, concise technical terms. Verification that the aircraft structure meets requirements is needed to assure the government that minimum performance has been attained and to demonstrate that the developer has met the obligations of the contract.

REQUIREMENT GUIDANCE (A.3)

Fulfill this requirement by tailoring the specification to assure that:

a. Minimum acceptable structural performance is stated in unambiguous terms.

b. Verification requirements are adequate to define the structural performance attained.

Discipline engineers should:

a. Tailor performance requirements to assure that the developed structure is adequate, including synergistic interrelationships with other structural disciplines, other technical areas, and broad system level disciplines in solid engineering and contractual language.

b. Specify analyses, tests, and inspections which synergistically and efficiently verify that these performance requirements are met.

Lead Engineers and Chief Functional Engineers should assure that:

a. Tailored requirements of the structural engineering disciplines are synergistically interrelated with other structural disciplines, other technical areas, and broad system level disciplines.

b. Tailored requirements are in accordance with higher level and system requirements.

REQUIREMENT LESSONS LEARNED (A.3)

The need for structural requirements and verification is apparent in mishap and accident records. Airframe and landing gear structural failures for 1968 through 1978 are synopsized in tables I through III. Overload refers to cases where the structure was at full design strength and failure was caused by loads exceeding local design strength. Design understrength means that the local design strength was inadequate to support design loads.

Although not included in this database, there were large numbers of failures of secondary structures. These included initial and secondary failures due to overload, understrength, vibration, acoustics, corrosion, water entrapment, hail, bird strike, tool drop, and many other causes.

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A.4 Verification.

The verification methodologies and the incremental process for completing the verification shall be identified in this section. The incremental verification shall be consistent with the expectations for design maturity expected at key decisions points in the program. Table _____ provides a cross-reference between the requirements and the associated method and timing of the verification. This table is used to identify and verify that all requirements have an associated verification and expected level of verification for the key decision points.

VERIFICATION RATIONALE (A.4)

VERIFICATION GUIDANCE (A.4)

See table IV as an example of a Structural Verification Matrix. This matrix should be tailored to the specific program key decision points and proposed incremental verification.

VERIFICATION LESSONS LEARNED (A.4)

A.3.1 Detailed structural design requirements.

The requirements of this specification reflect operational and maintenance needs and capabilities, and are stated in terms of parameter values, conditions, and discipline (loads, flutter, etc.) requirements. The air vehicle structure (airframe) shall have sufficient structural integrity to meet these requirements, separately and in attainable combinations.

REQUIREMENT RATIONALE (A.3.1)

This requirement is needed to ensure that all applicable structural design requirements are defined in engineering quantities in the specification to ensure that the airframe properly functions during the intended usage and that the structural integrity of the airframe is achieved and maintained. This requirement establishes the starting point for the design of the airframe and the conduct of the engineering analyses and tests to verify the adequacy of the design.

REQUIREMENT GUIDANCE (A.3.1)

The aim of this requirement is the conversion of the operational and maintenance needs of the aircraft into the specific structural design requirements that will drive the selection of the structural design criteria, structural designs, materials, fasteners, fabrication methods, etc. All expected operational and maintenance needs must be evaluated to ensure that the specific structural design requirements are complete and of sufficient detail to enable the design, analyses, fabrication and testing of the airframe to be undertaken.

The selection of each specific structural design requirement must be carefully made so that the airframe designed, built, and maintained to meet these requirements will have adequate structural integrity, acceptable economic cost of ownership, and acceptable structural performance in terms of aircraft performance capabilities and weight. Although in many cases past experience will provide the basis for the selection of the specific requirements, each selection must consider the impact of new design approaches, new materials, new fabrication methods, unusual aircraft configurations, unusual usage, planned aircraft maintenance activities, and past lessons learned.

There is a clear distinction between design requirements and design criteria. Design requirements establish a capability that the airframe must possess. Design criteria establish the engineering standards to be used to enable the airframe to achieve the required capability. For example, the factor of uncertainty is a design criteria and not a design requirement. The requirement is to have adequate ultimate load capability. The factor of uncertainty is one

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engineering method for achieving this requirement. Care should be taken to distinguish between design requirements and design criteria.

REQUIREMENT LESSONS LEARNED (A.3.1)

Prior to the 1950 time period, the service life expectancy of medium and heavy bomber aircraft was on the order of 1000-5000 flight hours. The missions' requirements were maximum range/payload high altitude weapon delivery. These requirements led to the use of new high strength aluminum alloys at relatively high stress levels. Very little emphasis was given to structural durability and damage tolerance.

When mission requirements for these aircraft changed to include high-speed low level operation over a much longer service life, many kinds of structural problems began to occur. Fatigue cracking initiated in areas of high stress concentration. The high strength alloys were susceptible to stress corrosion cracking and had low tolerance for fatigue cracking or other defects because of low fracture toughness.

Structural modifications to these aircraft that were designed to meet the more severe load environment and extended service life have been verified by extensive testing, analysis and service experience. Materials with higher fracture toughness, reduction of stress concentrations and use of durability and damage tolerance design concepts were incorporated in these life extension modifications.

A.4.1 Detailed structural design requirements.

The adequacy of the detailed structural design requirements contained in this specification shall be verified by the review of the documentation provided to substantiate the adequacy of the requirements. The air vehicle structure (airframe) shall be shown capable of achieving these requirements by applicable inspections, demonstrations, analyses, and tests. All verifications shall be the responsibility of the contractor; the Government reserves the right to witness or conduct any verification.

VERIFICATION RATIONALE (A.4.1)

The ability of the specified structural design requirements to adequately meet the operational and maintenance needs must be demonstrated to ensure that these needs will be met. This verification is achieved by reviewing the documentation that substantiates the selection of each specific design requirement to ensure that the requirement meets the program needs, reflects successful past experience, and has been updated to reflect new design approaches, new materials, etc.

VERIFICATION GUIDANCE (A.4.1)

The statement of the requirement alone is generally not sufficient to substantiate its adequacy. This substantiation is accomplished by the accompanying information which shows the adequacy of the requirement through comparisons with existing designs, through the results of design trade studies and analyses, and through the results of developmental tests.

VERIFICATION LESSONS LEARNED (A.4.1)

Durability and damage tolerance assessment programs have been accomplished on operational aircraft that were designed prior to 1970. In many cases documentation of analyses and tests performed during design and development were either not available or inadequate for the durability and damage tolerance assessment. In these cases the analyses and tests were repeated or expanded at considerable cost.

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The importance of adequate documentation of design and verification analyses and tests cannot be over emphasized.

A.3.1.1 Deterministic design criteria.

The deterministic structural design criteria stated in this specification are, as a minimum, those necessary to ensure that the airframe shall meet the detailed structural design requirements established in this specification. These criteria are also based on the requirements derived from the inherent operational, maintenance, engineering and test needs of the aircraft such as the location of and access to equipment and the loading and unloading of cargo or payload. Each individual criterion established herein has been selected based upon historical experience with adjustments made to account for new design approaches, new materials, new fabrication methods, unusual aircraft configurations, unusual usage, planned aircraft maintenance activities, and any other significant factors. Trade studies and analyses supporting the substantiation of the adequacy of these criteria in meeting the specified and inherent design requirements, and their use in design details, shall be documented in accordance with the verification requirements in 4.1.1.

REQUIREMENT RATIONALE (A.3.1.1)

This requirement is needed to ensure that the specific structural design criteria required to enable the airframe to achieve the operational, maintenance, engineering, and test needs are completely defined and are rationally related to the structural design requirements.

REQUIREMENT GUIDANCE (A.3.1.1)

The structural design criteria is the statement of the engineering standards that will be used to meet the structural design requirements and achieve the needed operational, maintenance, engineering, and test capabilities. These criteria are derived from and directly relatable to the specific design requirements. They provide critical information to the engineer on how to design, analyze, build, and test the airframe. It is important that the historically used criteria be thoroughly reviewed and, as appropriate, be updated to reflect the use of new design methods, new materials, new fabrication methods, unusual aircraft configurations, unusual usage, planned aircraft maintenance activities, and past lessons learned. The substantiation of the adequacy of the selected criteria is normally documented in the structural design criteria report.

REQUIREMENT LESSONS LEARNED (A.3.1.1)

A.4.1.1 Deterministic design criteria.

The detailed structural design criteria shall reflect all of the requirements of this specification and those derived from operational, maintenance, engineering, and test needs. This criteria shall be verified by the review of the documentation provided to substantiate the adequacy of the criteria.

VERIFICATION RATIONALE (A.4.1.1)

The ability of the structural design criteria to enable the airframe to meet the structural design requirements must be verified. This verification is achieved by reviewing the documentation that substantiates the selection of each specific design criterion to ensure that the design requirements are being met, that the criterion reflects past experience and lessons learned, and that the criterion has been modified to address circumstances outside the historical data base.

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VERIFICATION GUIDANCE (A.4.1.1)

The substantiation of the applicability of the structural design criteria to the particular aircraft being designed is accomplished by documenting that each criterion is supported by applicable past experience, appropriate analyses and trade studies, or design development tests. As each criterion is being selected, the overall structural design philosophy embodied by the criterion as well as the specific numeric values contained in the criterion must be reviewed to determine if it will meet the applicable structural design requirements. Special attention should be given to the selection of criteria which will be used in circumstances outside the historical data base. These circumstances include new design approaches, new materials, new fabrication methods, unusual aircraft configurations, unusual usage, and new aircraft maintenance methods.

VERIFICATION LESSONS LEARNED (A.4.1.1)

A.3.1.2 Probability of detrimental deformation and structural failure. (_____).

Only where deterministic values have no precedence or basis, a combined load-strength probability analysis shall be conducted to predict the risk of detrimental structural deformation and structural failure, subject to the approval of the procuring activity. For the design requirements stated in this specification, the airframe shall not experience detrimental structural deformations with a probability of occurrence equal to or greater than __________ per flight. Also, for these design requirements, the airframe shall not experience the loss of adequate structural rigidity or proper structural functioning such that flight safety is affected or suffer structural failure leading to the loss of the air vehicle with a probability of occurrence equal to or greater than ___________ per flight. Shipboard landings are per the multivariate distribution of landing impact conditions of ____.

REQUIREMENT RATIONALE (A.3.1.2)

This requirement establishes the maximum acceptable frequency of occurrence of detrimental deformation and structural failures that are used in conjunction with combined load-strength probability analyses.

REQUIREMENT GUIDANCE (A.3.1.2)

In some instances, historically based deterministic criteria are not applicable to the specific combination of design approaches, materials, fabrication methods, usage, and maintenance for the structural element being designed. In these instances, it may not be possible to rationally arrive at an alternative deterministic criteria and a combined load-strength probability analysis is conducted to establish that the risks of detrimental structural deformation and structural failure are acceptable. The selection of the maximum acceptable frequency of occurrence of detrimental structural deformation, loss of structural functioning or structural failure can be made by examining relevant historical repair and failure rates. A maximum acceptable frequency of permanent structural deformations would be 1×10^{-5} occurrences per flight. A maximum acceptable frequency of the loss of adequate structural rigidity or proper structural functioning, or structural failure leading to the loss of the air vehicle would be 1×10^{-7} occurrences per flight.

In most cases, a combined load-strength probability analyses is only selectively used in the analysis of the structural elements for which historically based deterministic criteria are not appropriate. In these cases, a probability analysis of a highly loaded representative structural element is performed. This analysis would address all of the significant variations in load, material properties, dimensions, etc. Once the design of the element has been completed by these probabilistic means, it is usually possible to develop a set of modified deterministic criteria

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which, when combined with the appropriate limit and ultimate loads, would yield the same final element design. This updated criteria can then be used to design similar structural elements. In addition to establishing new design criteria, the conduct of the probability analysis also aids in gaining an increased understanding of the more important design drivers and enables an improved design to be produced.

If combined load-strength probability analyses are not used, insert N/A (not applicable) in the first blank.

REQUIREMENT LESSONS LEARNED (A.3.1.2)

A.4.1.2 Probability of detrimental deformation and structural failure. (____).

The combined load-strength probability analyses shall be verified by the review of the documentation of the analyses and the review of supporting tests.

VERIFICATION RATIONALE (A.4.1.2)

The airframe must be demonstrated to have an acceptable risk of failure when historically based design approaches, fabrication methods, air vehicle usage, etc., are not used. This verification is achieved by reviewing the documentation of the probability analyses and the supporting test results.

VERIFICATION GUIDANCE (A.4.1.2)

The ability of the airframe to maintain an acceptable risk of structural failure when historically proven methods are not used can be demonstrated through the conduct of appropriate probability analyses and supporting tests. The documentation of these analyses and tests is the primary means of verifying the adequacy of the design of the airframe.

If combined load-strength probability analyses are not used, insert N/A (not applicable) in the first blank.

VERIFICATION LESSONS LEARNED (A.4.1.2)

A.3.1.3 Structural integrity.

The air vehicle shall meet the structural integrity requirements of this specification. These integrity requirements shall apply to all parts of the air vehicle including the airframe, actuators, fairings, seals, films, coatings, etc. Critical parts may have additional requirements designed to control their quality, durability, and/or damage tolerance.

A.3.1.3.1 Parts classification.

All air vehicle parts and components shall be classified for criticality.

A.3.1.3.2 Fatigue/fracture critical parts.

Fatigue/fracture critical parts shall meet the requirements of 3.11, 3.12, and the control processes of 3.13.

A.3.1.3.3 Maintenance critical parts.

Maintenance critical parts shall meet the requirements of 3.11 and 3.12.

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A.3.1.3.4 Mission critical parts.

In addition to the requirements of this specification, mission critical parts shall have special design criteria developed to meet the requirements of the air vehicle specification. In addition, special controls on quality, processes, and inspections may be required.

A.3.1.3.5 Fatigue/Fracture critical traceable parts.

Fatigue/fracture critical traceable parts shall meet the requirements of 3.11, 3.12, and the control processes of 3.13.

REQUIREMENT RATIONALE (A.3.1.3 through A.3.1.3.5)

REQUIREMENT GUIDANCE (A.3.1.3 through A.3.1.3.5)

REQUIREMENT LESSONS LEARNED (A.3.1.3 through A.3.1.3.5)

A.4.1.3 Structural integrity.

The requirements of 3.1.3 shall be met by analysis, inspection, demonstration, and test.

A.4.1.3.1 Parts classification.

The requirements of 3.1.3.1 shall be met by analysis, documentation, and inspection.

A.4.1.3.2 Fatigue/fracture critical parts.

The requirements of 3.1.3.2 shall be met by analysis, documentation, inspection, and test.

A.4.1.3.3 Maintenance critical parts.

The requirements of 3.1.3.3 shall be met by analysis, documentation, and inspection.

A.4.1.3.4 Mission critical parts.

The requirements of 3.1.3.4 shall be met by examination, analysis, documentation, and inspection.

A.4.1.3.5 Fatigue/fracture critical traceable parts.

The requirements of 3.1.3.5 shall be met by analysis.

VERIFICATION RATIONALE (A.4.1.3 through A.4.1.3.5)

VERIFICATION GUIDANCE (A.4.1.3 through A.4.1.3.5)

VERIFICATION LESSONS LEARNED (A.4.1.3 through A.4.1.3.5)

A.3.2 General parameters.

The airframe shall have sufficient structural integrity to meet the required operational and maintenance capabilities reflected in the parameters of 3.2 and subparagraphs and attainable combinations of the parameters. These parameters are to be used in conjunction with the conditions and discipline requirements of this specification.

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REQUIREMENT RATIONALE (A.3.2)

This set of general requirements is needed to collectively define conditions of usage that are mutually applicable to the following discipline requirements, for example 3.4, Structural Loading Conditions. Further, the operational and maintenance capability required of the airframe from a strength, rigidity, and aeroelasticity viewpoint are to be identified and established in measurable engineering terms and parameters.

REQUIREMENT GUIDANCE (A.3.2)

The general parameters of this paragraph are to be used in conjunction with the other requirements of this specification to define the total structural requirements for the airframe. Before the hardware (airframe) exists and in particular, before the contract for the hardware is written, it is impossible to select the one combination of the specification parameters which will be the worst strength, rigidity, and aeroelasticity conditions to be experienced by the airframe during its usage. If one such condition could be defined, it would greatly reduce the time and cost of designing, developing, testing, and verifying the airframe. Note that a conservative condition could be chosen, however, it would not be experienced by the airframe during usage and hence the airframe would be over-designed and probably weigh and cost more than it should. Also, an unconservative condition could be chosen, but this would result in higher maintenance and repair costs and higher attrition rates. Therefore, it is necessary to define each of the specification parameters to the extent possible and assess the contribution to the required airframe structural integrity of each attainable combination of those parameters.

REQUIREMENT LESSONS LEARNED (A.3.2)

Not all usage of the airframe during flight operations needs to be covered by the parameters and conditions of the specification. For example, a fighter collided with a 1190-foot tall television transmitter tower approximately 100 feet below its top. The aircraft was on an annual tactical qualification check flight as lead of a three ship wedge formation. Numbers two and three were flying 3,000 feet abreast, 1-1/2 nautical miles (NM) in trail. Number three saw a puff of smoke and the top section of the tower fall. Visual inspection revealed the loss of the left drop tank and left wing tip, as well as two deep gashes in the leading edge of the left wing. The aircraft was recovered. It would not be prudent to design all low level flying aircraft for collisions with towers because it does not happen very often. However, it is prudent to design them for collisions with birds since experience shows impacts with birds occur at significant levels of probability of occurrence, whereas impacts with towers occur very, very infrequently.

A.4.2 General parameters.

Analyses, tests, and inspections shall be in compliance with the following subparagraphs to show that the airframe meets the operational and maintenance capabilities required in 3.2.

VERIFICATION RATIONALE (A.4.2)

These verification tasks are needed to show that the airframe does in fact perform as required and possesses sufficient structural integrity to perform as required, as often as required.

VERIFICATION GUIDANCE (A.4.2)

Many of the general parameter requirements can be verified by those inspections, analyses, and tests needed to verify that the discipline requirements have been met. Integrated verification tasks that can verify several requirements at once are to be encouraged.

VERIFICATION LESSONS LEARNED (A.4.2)

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A.3.2.1 Airframe configurations.

The airframe configurations shall encompass those applicable to flight and ship-based/ground conditions and reflect authorized usage of the air vehicle.

REQUIREMENT RATIONALE (A.3.2.1)

This requirement is needed to assure that the airframe structure can operate satisfactorily during all specified operating/maneuvering conditions while in the worst considered/expected configuration for each condition. Configurations might include basic, high drag, dive recovery, landing approach, takeoff, external loadings, etc.

REQUIREMENT GUIDANCE (A.3.2.1)

All configurations that the airframe can be put into must be considered in conjunction with other operational requirements to ensure adequate structural integrity exists. Sometimes the configurations of concern are the different combinations of selected missiles or other airborne stores.

REQUIREMENT LESSONS LEARNED (A.3.2.1)

An analytical and test program was conducted for a fighter airframe to determine the airframe's capability to fly with many variations of an air-to-air missile. See figures 1 and 2 regarding the spread of weight, inertia, and center of gravities considered for that program.

A.4.2.1 Airframe configurations.

Contractor selected and acquisition agency approved configurations shall be verified during tests.

VERIFICATION RATIONALE (A.4.2.1)

Verification that all required configurations can be achieved is needed to confirm that the air vehicle will be able to perform as intended.

VERIFICATION GUIDANCE (A.4.2.1)

Most configurations can be verified by inspection, for example, external store configurations. Some configurations may need to be verified by test measurements, for example, flap deflections or wing sweep positions on sweep wing airplanes.

VERIFICATION LESSONS LEARNED (A.4.2.1)

A.3.2.2 Equipment. (_____)

The airframe shall support and react the loads and motion of all equipment required and expected to be carried by the air vehicle. This equipment includes ____________________.

REQUIREMENT RATIONALE (A.3.2.2)

The intent of this requirement is to ensure that all equipment, including government furnished equipment, is adequately supported and their loads and motion have been considered.

REQUIREMENT GUIDANCE (A.3.2.2)

Equipment mass properties and loads, like thrust, frequently change during development. They must be constantly monitored and the analysis of the airframe adjusted as necessary. The equipment list should include CFE, GFE, and equipment installed after delivery.

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REQUIREMENT LESSONS LEARNED (A.3.2.2)

Typical engineering approaches involve the identity of the larger vehicles for which space and mass are a primary concern, identity of maximum dual and single wheel axle loadings, identity of maximum running loads for tracks and pallets, and the use of running loads and volumetric block loadings to address the multitude of palletized and loose supplies. Careful attention to the off center loadings permitted is required.

Cargo listed may be in the design/development phase. There is a risk that the vehicle design parameters could change during its development phase and thereby exceed the airframe's parameters, which were based on the original air vehicle parameters. Close coordination between the air vehicle developer and airframe system program office is required to reduce this risk, and insure that the most up-to-date vehicle parameters are used.

A.4.2.2 Equipment. (____).

The analyses, tests, and inspections required by this specification shall be sufficient to show that the airframe adequately supports and reacts all of the loads and motions of the equipment defined in 3.2.2.

VERIFICATION RATIONALE (A.4.2.2)

Verification of the airframe ability to react all the loads and motion is necessary to ensure that the operational mission needs can be achieved by the air vehicle.

VERIFICATION GUIDANCE (A.4.2.2)

Verification will be by load and strength analyses supported by ground and flight test.

VERIFICATION LESSONS LEARNED (A.4.2.2)

A.3.2.3 Payloads. (_____)

The airframe shall support and react the loads and motions of payloads required and expected to be carried by the air vehicle. These payloads include __________________.

REQUIREMENT RATIONALE (A.3.2.3)

When a payload is carried, the weapon system is to carry and deliver that payload without inducing failure or damage to the aircraft or payload.

REQUIREMENT GUIDANCE (A.3.2.3)

Identify those documents, figures, tables, etc. which define the payload to be carried by the air vehicle. Payloads include such items as passenger, passenger baggage, cargo (vehicles, crated and palleted equipment or freight, etc.), stores (bombs, rockets, etc.), ammunition, flare, chaff, and disposable fuel tanks. External fuel tanks intended to be routinely returned to base should be accounted for in operating weight.

REQUIREMENT LESSONS LEARNED (A.3.2.3)

Typical engineering approaches involve the identification of the larger vehicles for which space and mass are a primary concern, identification of maximum dual and single wheel axle loadings, identification of maximum running loads for tracks and pallets, and the use of running loads and volumetric block loadings to address the multitude of palletized and loose supplies. Careful attention to the permitted, off center loadings is required.

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Payload listed may be in the design/development phase. There is a risk that the payload design parameters could change during its development phase and thereby exceed the airframe's parameters which were based on the original air vehicle parameters. Close coordination between the air vehicle developer and air vehicle systems program office is required to reduce this risk, and insure that the most up-to-date vehicle parameters are used.

A.4.2.3 Payloads. (___)

The analyses, tests, and inspections required by this specification shall be sufficient to show that the airframe has the ability to support and react all of the loads and motions of the payload defined in 3.2.3.

VERIFICATION RATIONALE (A.4.2.3)

Verification of the airframe's payload carrying capability is needed to assure that the operational mission needs can be achieved by the air vehicle.

VERIFICATION GUIDANCE (A.4.2.3)

The capability of the airframe to carry the required payload must be determined and verified. Load and strength analyses are supported by ground and flight tests to ensure that the airframe has the required capability.

VERIFICATION LESSONS LEARNED (A.4.2.3)

A.3.2.4 Weight distributions.

The air vehicle weight distributions shall be those required for operations and maintenance use.

REQUIREMENT RATIONALE (A.3.2.4)

Weight distributions need to be known since they effect all aspects of usage of the air vehicle, including performance, aircraft balance, handling qualities, loads, aeroelasticity and structural responses, stresses, etc.

REQUIREMENT GUIDANCE (A.3.2.4)

Weight variations of individual mass items are included as part of this requirement, particularly if large variations in weight of an item can exist. Other aspects to consider, especially when one air vehicle system is or will be sold to many different countries, includes establishment of the actual center of gravity margins for all versions; definition of the limits of pilot and associated equipment weights; determination of configurations most critical for forward and aft center of gravity conditions; and definition of minimum ballast required.

REQUIREMENT LESSONS LEARNED (A.3.2.4)

Weight and weight distributions can and will become a real problem if many configurations are sold to many customers/countries and if a weight control program is not initiated. In 1975 a potentially critical problem developed in the application of pilot weight criteria for the design of ballast weights. The inconsistent application of the light (150 lbs), nominal (240 lbs), and heavyweight (280 lbs) pilot weight (along with other variables such as fuel density, i.e., JP-4 or JET A-1) coupled with the highly critical center of gravity could produce couplings and loadings in excess of values based on nominal assumptions. A mutually agreeable policy between the SPO and the contractor concerning the application of the various weights noted above was established. The policy decision was, "For future design, analysis testing, and qualification the most adverse combinations of pilot weight, fuel weight, and ballast shall be considered. The maximum pilot weight need not exceed a combined weight of 200 pounds for the pilot, personal

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items, parachute, and survival vest. The minimum pilot weight need not be less than a combined weight of 150 pounds for the pilot, personal items, and parachute. Variable ballast shall be considered in a rational manner. For formal weight reports, weight reference sheets and Prime Item Development Specifications, a nominal combined pilot weight of 240 pounds including personal gear and parachute will be required along with the fuel weight for the prime fuel used. For maximum and minimum weight conditions, informal weight reports, weight reference sheets, and Prime Item Development Specifications, use the most adverse combinations of fuel weight, variable ballast, and pilot weight."

A.4.2.4 Weight distributions.

Weight distributions shall be verified by analyses. The following weight distributions shall also be verified by test: _________________.

VERIFICATION RATIONALE (A.4.2.4)

Verification of the weight distributions is needed to assure that errors do not invalidate flight or ground performance established for the vehicle, for example, external loads, which rely on the weight distributions of the air vehicle being established and actually known.

VERIFICATION GUIDANCE (A.4.2.4)

Weight distributions can be established using analytical techniques. These numbers can normally be used with confidence. Weighings, ground vibration tests, and tests run to determine moments of inertia can be used to verify weight distributions. Insert in the blank those weight distributions to be verified by test.

VERIFICATION LESSONS LEARNED (A.4.2.4)

A.3.2.5 Weights.

The weights to be used in conducting the design, analysis, and test of the air vehicle are derived combinations of the operating weights, the defined payload, and the fuel configuration. These weights shall be the expected weight at Initial Operation Capability (IOC).

REQUIREMENT RATIONALE (A.3.2.5)

Requirements which define the ranges of weight which the air vehicle will experience during its usage are needed since these weights directly influence the structural performance of the airframe.

REQUIREMENT GUIDANCE (A.3.2.5)

In each of the subparagraphs, provide the definition of the configuration of the air vehicle that corresponds to the weight (not the number) starting with operating weight and adding the required payload and usable fuel. Operating weight is defined in MIL-W-25140. A weight growth factor is to be applied in each weight definition to predict an IOC weight (see Lessons Learned). For modification programs, provide growth in relation to the modification weight only. Care should be taken in the placement of the growth weight. The effect of the weight placement could affect control surfaces. The actual baseline weight of the aircraft to be modified shall be validated.

The actual air vehicle weights corresponding to the weight configurations defined in this specification are usually defined in the structural design criteria report.

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REQUIREMENT LESSONS LEARNED (A.3.2.5)

Experience has shown that aircraft weight will grow between source selection or contract signing and IOC for a variety of reasons. It will also grow after IOC as witnessed by the Air Force multi-role fighter as a pound a day. The primary reason for the initial weight growth is because requirements may not be well defined. That is, the geometry may change (spars, bulkheads, skin thicknesses, etc.), equipment ('black boxes', hydraulics, etc.) may have changed due to better understanding of the mission, loads may have been optimistic, the government furnished equipment (like engines) weight may have matured, the material properties may have been optimistic, and other such reasons. Other reasons for weight growth are optimism in the weights estimates, insufficient schedule for development, lack of funds and the lack of management support for mass properties. All services have experienced aircraft weight growth in this period. Using IOC weights for analysis eliminated the iteration of analysis each time weight changes took place during the development process.

There is a need to combat weight growth to protect the advertised performance, to protect the required structural integrity, and to restore political confidence in the acquisition process. There are many ways to combat weight growth. One of the best ways is to remove the optimism in the weight prediction. A weight reconciliation process in which the contractor and the government compare weights and agree on what the weight should be may help to reduce over-optimistic weight estimates. But that should only be a part of the solution to minimize the weight growth. Other methods may be strong configuration management, a weight margin, zero weight growth development, adequate performance margins, incentive fee program, or a combination of the above. A good mass properties management and control process is required.

A fighter airplane basic landing weight (BLW) is 15,000 pounds for all configurations. This weight is a deviation from existing requirements which would have required a BLW of 17,418 pounds. But because the primary mission was 85 percent air-to-air and performance was not to be degraded by any alternate mission, the 15,000 pound value was not changed. The wheel jacking weight was established in accordance with MIL-A-008862 and no problems have occurred in this area.

The strong consideration toward lightweight design of a large transport resulted in the selection of lightweight wiring and electronic controls using hybrid driver circuits. The weight savings were significant. Some areas of the aircraft developed maintenance problems. The landing gear actuation controls were particularly susceptible to intermittent failures and difficult to evaluate and were redesigned and replaced. Some 800 feet of 26 gauge wire were suspected of contributing to the failures and replaced. A total of 311,000 feet of the wire has performed with reasonable success for over 10 years, but later versions of the aircraft using similar insulation on heavier gauge wire are being substituted to avoid future maintenance problems. Careful consideration of where new technology can be successfully used must be evaluated during initial design to avoid costly rework.

Aircraft wire weights. In a bomber development it was found that the contractor's design practice for wire bundles was to provide extra wires to allow for broken wires and subsystem growth. No trades to evaluate the weight impact and maintenance advantages were made to validate this practice or to optimize the number of extra wires.

Bomber and cargo weight trends. Figure 3 shows the percentage breakdown of the various weight items which comprise the take-off gross weight of past bomber and cargo aircraft. Table V shows the average yearly growth for several weights of past bombers and cargo aircraft.

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A.3.2.5.1 Operating weight.

The operating weight is the weight empty plus oil, crew, unusable fuel, and __________.

REQUIREMENT RATIONALE (A.3.2.5.1)

The operating weight is used as the basis for all weight definitions in this specification.

REQUIREMENT GUIDANCE (A.3.2.5.1)

See MIL-W-25140 - include guns, other fixed useful load items, and special mission equipment (weapon racks, pylons, tiedown equipment, etc.) as per MIL-STD-1374.

REQUIREMENT LESSONS LEARNED (A.3.2.5.1)

A.3.2.5.2 Maximum zero fuel weight.

The maximum zero fuel weight shall be the highest required weight of the loaded air vehicle without any usable fuel and is specified as the operating weight plus __________.

REQUIREMENT RATIONALE (A.3.2.5.2)

This requirement defines the highest aircraft weight without usable fuel.

REQUIREMENT GUIDANCE (A.3.2.5.2)

The normal definition for maximum zero fuel weight is the operating weight plus maximum payload.

REQUIREMENT LESSONS LEARNED (A.3.2.5.2)

A.3.2.5.3 Minimum flight weight.

The minimum flight weight shall be the lowest weight required for flight and is specified as __________.

REQUIREMENT RATIONALE (A.3.2.5.3)

This requirement defines the lightest weight of the aircraft for design purposes.

REQUIREMENT GUIDANCE (A.3.2.5.3)

The normal definition of minimum flight weight is the weight empty per MIL-STD-1374 plus the minimal crew, unusable fuel, oil, minimal equipment, and five percent of the total usable internal fuel capacity or reserve fuel as specified in the detailed specification.

REQUIREMENT LESSONS LEARNED (A.3.2.5.3)

Care must be taken in defining minimum flying weight. A recent attack aircraft minimum flying weight included 250 ammo cases. Because of this, the aircraft balance was determined to include these 250 cases. Therefore, whenever the aircraft flew, it had to carry the cases or ballast to keep it within the c.g. limits.

A.3.2.5.4 Basic flight design gross weight.

The basic flight design gross weight shall be the highest flight weight required for the maximum positive and minimum negative load factors of 3.2.9.1 maneuvering flight and is specified as the operating weight plus ___________.

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REQUIREMENT RATIONALE (A.3.2.5.4)

This requirement defines the highest and lowest product of load factor and weight required for the aircraft.

REQUIREMENT GUIDANCE (A.3.2.5.4)

The normal definition of basic flight design gross weight is:

a. For bombers, cargo, observation, trainers, and utility aircraft, the flight design gross weight is the weight at engine start with the primary mission payload and fuel load.

b. For attack and fighter aircraft the flight design gross weight is the greater of the following:

(1) The maximum flight weight minus 50% of the maximum internal and external payload for which provisions are made with either full internal fuel or 80% of total fuel (internal plus external) whichever is greater. The basis for fuel weight is the fuel at engine start.

(2) The take-off weight with primary useful load, including either full internal or 80% of the total fuel (internal and external) whichever is greater for land based aircraft and primary useful load plus 60% of the internal fuel for ship based aircraft. The basis for external fuel weight is the fuel at engine start.

REQUIREMENT LESSONS LEARNED (A.3.2.5.4)

A.3.2.5.5 Maximum flight weight.

The maximum flight weight shall be the highest weight required for flight and is specified as the operating weight plus ___________.

REQUIREMENT RATIONALE (A.3.2.5.5)

This requirement defines the highest flight gross weight which will be provided for in the design.

REQUIREMENT GUIDANCE (A.3.2.5.5)

The normal definition of maximum flight weight is the operating weight of the aircraft plus maximum internal and external payload and maximum internal and external fuel. Care should be taken when addressing aircraft with inflight refueling capability. In these aircraft, the maximum flight weight may exceed the maximum takeoff weight.

REQUIREMENT LESSONS LEARNED (A.3.2.5.5)

A.3.2.5.6 Landplane landing weight.

The landplane landing weight shall be the highest landing weight for the maximum land based sink rate and is specified as the operating weight plus ___________.

REQUIREMENT RATIONALE (A.3.2.5.6)

This requirement defines the highest weight which is to be used in combination with the maximum sink speed consistent with the intended use of the weapon system.

REQUIREMENT GUIDANCE (A.3.2.5.6)

The normal definition of landplane landing weight is:

a. For observation, trainers, and utility aircraft, the maximum flight weight minus all payload items expected to be expended, all external fuel, and 25 percent internal fuel.

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b. For cargo aircraft, the maximum flight weight minus all external fuel and 50 percent internal fuel.

c. For bombers, attack, and fighter aircraft, the maximum flight weight minus all external fuel and 60 percent internal fuel.

REQUIREMENT LESSONS LEARNED (A.3.2.5.6)

A.3.2.5.7 Maximum landing weight.

The maximum landing weight shall be the highest weight required for any landing and is specified as the operating weight plus ___________.

REQUIREMENT RATIONALE (A.3.2.5.7)

This requirement defines the highest landing weight required for design purposes.

REQUIREMENT GUIDANCE (A.3.2.5.7)

The normal definition of maximum landing weight is the maximum flight weight minus assist-takeoff fuel, droppable fuel tanks, items expended during routine take-off, and fuel consumed or dumped during one go-around or 3.0 minutes, whichever results in the minimum amount of fuel.

REQUIREMENT LESSONS LEARNED (A.3.2.5.7)

A.3.2.5.8 Maximum ground weight.

The maximum ground weight shall be the highest weight required for ramp, taxiway, and runway usage and is specified as the operating weight plus ____________.

REQUIREMENT RATIONALE (A.3.2.5.8)

This requirement defines the highest ground weight required for design purposes.

REQUIREMENT GUIDANCE (A.3.2.5.8)

This weight is frequently referred to as maximum ramp weight. It is used for ground handling, jacking, taxiing, and runway usage. It is usually higher than the maximum take-off weight by the amount of fuel used in taxiing the aircraft for take-off.

REQUIREMENT LESSONS LEARNED (A.3.2.5.8)

A.3.2.5.9 Maximum take-off weight.

The maximum take-off weight shall be the highest required weight for flight usage at the time of lift-off and is specified as the operating weight plus __________.

REQUIREMENT RATIONALE (A.3.2.5.9)

This requirement defines the heaviest take-off weight for design purposes.

REQUIREMENT GUIDANCE (A.3.2.5.9)

The maximum take-off weight is normally defined as the weight of the aircraft with the maximum internal and external loads and full fuel except for fuel used during taxi and warm-up.

REQUIREMENT LESSONS LEARNED (A.3.2.5.9)

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A.3.2.5.10 Maximum landing gear jacking weight.

The maximum landing gear jacking weight shall be the highest weight required for landing gear jacking and is specified as the operating weight plus ___________.

REQUIREMENT RATIONALE (A.3.2.5.10)

This requirement defines, for design purposes, the highest weight that can be jacked at the landing gear for purposes of wheel and brake changes.

REQUIREMENT GUIDANCE (A.3.2.5.10)

The maximum landing gear jacking weight is normally the maximum ground weight since it is desired not to offload fuel and payload when a tire change is required.

REQUIREMENT LESSONS LEARNED (A.3.2.5.10)

A.3.2.5.11 Maximum airframe jacking weight.

The maximum airframe jacking weight shall be the highest weight required for jacking on the airframe at locations other than the landing gear and is specified as the operating weight plus ____________.

REQUIREMENT RATIONALE (A.3.2.5.11)

This requirement defines, for design purposes, the highest weight at which the airframe may be jacked at locations other than the landing gear.

REQUIREMENT GUIDANCE (A.3.2.5.11)

This weight is usually defined as the maximum ramp weight minus the crew and passengers and is used to define the jacking point loads and related structure.

REQUIREMENT LESSONS LEARNED (A.3.2.5.11)

A.3.2.5.12 Hoisting weight.

The hoisting weight shall be the highest weight required for hoisting at the designated hoisting points considering combinations of hoisting points and is specified as the operating weight plus __________.

REQUIREMENT RATIONALE (A.3.2.5.12)

This requirement defines the highest weight at which the aircraft may be hoisted.

REQUIREMENT GUIDANCE (A.3.2.5.12)

This weight is usually defined as the maximum ramp weight minus the crew and passengers, and is used to design the hoisting point loads and related structures. This is to allow for a more timely removal of an aircraft disabled on a runway.

REQUIREMENT LESSONS LEARNED (A.3.2.5.12)

A.3.2.5.13 Maximum catapult design gross weight. (____)

The Maximum Catapult Design Gross Weight shall be the maximum catapult launch weight to be used to determine maximum tow force and in determining maximum launch Constant Selector Valve (CSV) settings and is specified as the operating weight plus _____________.

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REQUIREMENT RATIONALE (A.3.2.5.13)

This requirement defines the highest weight at which the maximum catapult tow force will be determined for design purposes.

REQUIREMENT GUIDANCE (A.3.2.5.13)

The weight of the airplane with maximum internal fuel and maximum external load for which provision is required, without any reduction permitted for fuel used during pre-launch operations.

REQUIREMENT LESSONS LEARNED (A.3.2.5.13)

This weight, which is used to determine the limit tow force loads, is normally the maximum mission weight plus an anticipated weight growth factor (IOC plus 10% weight empty). Almost every current Navy carrier aircraft has experienced significant weight growth and without a pre-design growth capability, the ship speed and available wind over deck would be insufficient, within the structural design to provide the required launch end speed. The maximum launch tow force resulting from this weight will be used to determine the maximum CSV setting in the launch bulletins to preserve static demonstrated strength.

A.3.2.5.14 Maximum catapult weight. (____)

The maximum catapult weight shall be the maximum launch weight for which shipboard launch is required within the structural limits of the airframe, wind over deck (WOD) capability, and launch end speed of the ship system and is specified as the operating weight plus ____________

REQUIREMENT RATIONALE (A.3.2.5.14)

This requirement defines the highest weight at which the aircraft can be safely launched based on the design tow force, most capable catapult, maximum ship speed, and wind over deck.

REQUIREMENT GUIDANCE (A.3.2.5.14)

Based on ship speed, wind over deck, and maximum catapult end speed, the maximum launch weight can be determined. This weight should be used to determine airframe strength limits.

REQUIREMENT LESSONS LEARNED (A.3.2.5.14)

Rather than determine gear stretch capability/limitations, based on improved catapult energy capability and increased weight growth after the aircraft is fielded and contractor support and flight test support is no longer available, this determination should be provided during EMD.

A.3.2.5.15 Primary catapult mission weight. (____)

The primary catapult mission weight is the minimum weight used to determine the maximum horizontal acceleration used in setting launch bulletin limits and is specified as the operating weight plus ________________.

REQUIREMENT RATIONALE (A.3.2.5.15)

This requirement defines the weight at which the maximum N_X (horizontal load factor) will be determined, based on maximum tow force and maximum thrust.

REQUIREMENT GUIDANCE (A.3.2.5.15)

This weight corresponds to the primary mission for each catapult separately.

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REQUIREMENT LESSONS LEARNED (A.3.2.5.15)

The N_X value is used to determine both mass item design requirements resulting from minimum weight launches and to establish catapult/weight CSV setting limitations.

A.3.2.5.16 Carrier landing design gross weight. (____)

The carrier landing design gross weight shall be the maximum aircraft weight that shipboard recovery can be initiated and shall be based on the ability to perform ___ passes and fly ____ nautical miles with _____ payload.

REQUIREMENT RATIONALE (A.3.2.5.16)

This requirement defines the highest weight at which shipboard landings/arrestments and shore-based FCLP (Field Carrier Landing Practices), and Navy Field Landings will be determined for design purposes.

REQUIREMENT GUIDANCE (A.3.2.5.16)

This weight is the maximum weight of a fully loaded aircraft (stores, gun, ammunition, pylons, racks, launchers, ejectors, empty fuel tanks, pods, etc.) minus the weight of all allowable expendables, minus the weight of all usable fuel plus the specified bring-back payload (fuels and stores).

REQUIREMENT LESSONS LEARNED (A.3.2.5.16)

This weight is used to determine the maximum recovery bulletin shipboard landing weight and airframe shipboard design loads and energy absorption requirements.

A.3.2.5.17 Barricade design gross weight. (_____)

The maximum weight at which shipboard barricade recovery can be initiated and is specified as the operating weight plus __________.

REQUIREMENT RATIONALE (A.3.2.5.17)

This requirement defines the highest weight at which emergency shipboard barricade engagements are required for design purposes.

REQUIREMENT GUIDANCE (A.3.2.5.17)

This weight is the normal equivalent to the carrier landing design gross weight, and along with engaging speed, is used to set barricade recovery limits, based on results of shore-based barricade tests.

REQUIREMENT LESSONS LEARNED (A.3.2.5.17)

This weight and the allowable MK-7 MOD 2 Barricade characteristics will determine the strap loads to be used for on-center and off-center ultimate loads, and the resultant airframe design requirements resulting from this condition. Airframe design configuration should be such that propeller placement or sharp leading edges will not damage the barricade straps. Also based on location of external stores, strap loads will impinge on them causing load conditions for configuration/design consideration.

A.3.2.5.18 Other weight.

The air vehicle, fuel, and payload configuration to be used in determining the design weights for other conditions and the corresponding design conditions are as follows: ____________.

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REQUIREMENT RATIONALE (A.3.2.5.18)

This requirement defines all other weights used in the design such as limiting wing fuel allowable weight, in-flight system failures, ground system failures, etc.

REQUIREMENT GUIDANCE (A.3.2.5.18)

These weights are usually defined in word definition form. They are used to define special air vehicle weight configurations other than those defined above which are critical in the designing the air vehicle. For example, Limiting Wing Fuel Allowable Gross Weight is the weight above which any additional load must be fuel carried in the wing.

REQUIREMENT LESSONS LEARNED (A.3.2.5.18)

A.4.2.5 Weights.

The weight shall be assessed throughout the development program and validated by actual weighing.

VERIFICATION RATIONALE (A.4.2.5)

Verification of the analytical weight values by weighing is needed to confirm that this parameter (weight) is as expected because it so greatly influences the structural capability of the airframe.

VERIFICATION GUIDANCE (A.4.2.5)

Verification shall be a continuing task through all phases of the program (estimated, calculated, and actual). Pieces and parts shall be verified by calculation as drawings are released and actual weighing when parts are available. Each aircraft will be weighed in a completely assembled and dry condition in accordance with MIL-W-25140. Corrections and analysis will be performed to verify each of the weights in this paragraph and the specifications. "Manufacturing Variation" shall be investigated to ascertain the cause and to control the aircraft mass properties.

VERIFICATION LESSONS LEARNED (A.4.2.5)

A.3.2.6 The center of gravity.

The center of gravity envelopes shall be commensurate with the requirements in the detailed specification and all the weights in 3.2.5 plus and minus a tolerance to account for manufacturing variations, addition of planned equipment, variations in payload, flight attitudes, density of fuel, fuel system failures of 3.2.22, and __________.

a. The tolerance is ___________.

b. The envelope is ____________.

REQUIREMENT RATIONALE (A.3.2.6)

Depending upon the type of airframe program, a requirement for tolerance is necessary since no airframe can be built that does not vary somewhat from the drawings and experience variations in loadings with usage. For example, a small modification program may not require a large tolerance. As a general rule, any time a change is made to the airframe, the weight goes up and the center of gravity goes aft. This is an application of Murphy's law. Failure to provide for rational tolerances and loadings can result in ballast requirements which result in additional weight.

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REQUIREMENT GUIDANCE (A.3.2.6)

Provide the center of gravity tolerance which is compatible with the type of air vehicle. Evaluate the applicability of the historical 1.5 percent of the mean aerodynamic chord prior to using it as a requirement. Rigorous evaluation of the effects of fuel redistribution at extreme attitudes has been used as an alternative to arbitrary center of gravity tolerances for some aircraft.

REQUIREMENT LESSONS LEARNED (A.3.2.6)

Loads calculations for a fighter model change were based on center of gravity positions in the 30 degree nose down attitude. Additionally, 1.5 percent further aft tolerance on the center of gravity positions in the 30 degrees nose up attitude was used. It was not felt necessary to calculate or determine loads with a 1.5 percent forward tolerance.

Fuel/center of gravity management system. Failure of monitoring systems which allow differences between primary and secondary systems without alerting the aircrew will degrade safety and mission performance requirements and could result in an unstable aircraft. The FCGMS failure monitoring system for a swing wing bomber allows differences between the primary and secondary system center of gravity calculations without alerting the pilots. This becomes critical, when, unknown to the pilot, incorrect input data is utilized by the system in control. The result is that the center of gravity computation/control will be in error and could drive the aircraft out of limits. The condition will also exist where the center of gravity calculation would not warn the pilots that a selected weapon release will cause the aircraft to immediately exceed limits. The aircraft specification required that under any operational condition a single failure of the fuel system shall not prevent the weapon system from completing its mission. A central test system and internal software checks were designed into the FCGMS to detect computer error, but not to compare systems. Undetected failure of the FCGMS monitoring system will adversely affect safety and mission performance. Attainable center of gravity positions, such as indicated above, need to be considered for inclusion and coverage in 3.2.14.

For the swing wing bomber, no tolerance was applied to the most forward and most aft center of gravity positions resulting from practical loading conditions and considering fuel transfer rates and wing sweep operational rates. Since the aircraft had an automatic fuel management control system, errors or changes in predicted c.g. locations were accounted for by adjustment of the fuel management control system.

A.4.2.6 The center of gravity.

The center of gravity position of the weights in 3.2.5 shall be verified by actual weighing of an empty aircraft, fuel calibration, and analysis.

VERIFICATION RATIONALE (A.4.2.6)

Determination of the applicable center of gravities analytically is needed to establish the aircraft's characteristics, including flight characteristics, performance, etc., as well as the airframe structural characteristics. However, these analytical values of center of gravities may or may not represent the actual hardware. Actual weighings of selected weight configurations are needed to verify the center of gravity values or to indicate where discrepancies exist so that the analytical results can be corrected to agree with actual measurements.

VERIFICATION GUIDANCE (A.4.2.6)

Identify and list those weights of 3.2.5 and the applicable center of gravities of weight distributions of 3.2.4 which are to be verified by actual weighings. The weights and weight

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distributions selected for verification of center of gravity positions should be included among those required in 4.2.5 so as to be cost effective.

VERIFICATION LESSONS LEARNED (A.4.2.6)

Limiting actual weighing of aircraft to the empty weight configuration has proven satisfactory on a large number of transport aircraft. Actual weighings and inertia measurements of external stores and internal payloads to be used in development flight test is recommended as these test stores and payloads have proven in the past to be unrepresentative of operationally configured stores and payloads.

A.3.2.6.1 Lateral center of gravity position.

The lateral center of gravity envelope shall be commensurate with the requirements in the detailed specification and all weight defined in 3.2.5. The envelope shall consider all asymmetrical store loading conditions which result in the lesser of the following rolling moments:

a. ___ times the maximum rolling moment attainable by loading each store station, with all possible combinations of pylons, adapters, launchers, racks and stores specified to be carried by that store station. As each store station is loaded, all other stations shall be empty of everything but an air worthy pylon.

b. Maximum attainable loading of one side of the aircraft with the other side empty of everything except air worthy pylons.

REQUIREMENT RATIONALE (A.3.2.6.1)

This requirement provides operational capability for both flight and shipboard or shore-based landing with asymmetric or dissimilar stores on opposing store stations.

REQUIREMENT GUIDANCE (A.3.2.6.1)

The required lateral c.g. for design purposes is based on either 120% of the maximum loading of any single store station or the maximum attainable by loading one side of the aircraft, plus the maximum wing asymmetric fuel allowed operationally without limitations.

REQUIREMENT LESSONS LEARNED (A.3.2.6.1)

Due to both inertia effects and aerodynamic effects, airframe trim loads required for symmetric flight can significantly increase maneuver loads or cause severe restrictions in flight operations. Due to inertia loads, landing gear energy requirements and resultant landing loads are increased due to store asymmetries.

4.2.6.1 Lateral center of gravity position.

The lateral center of gravity position of the weights in 3.2.5 shall be verified by actual weighing of an empty aircraft, fuel calibration, and by analysis.

VERIFICATION RATIONALE (A.4.2.6.1)

VERIFICATION GUIDANCE (A.4.2.6.1)

VERIFICATION LESSONS LEARNED (A.4.2.6.1)

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A.3.2.7 Speeds.

The following speeds and any attainable lesser speeds are applicable for ground and flight use of the air vehicle considering both required and expected to be encountered critical combinations of configurations, gross weights, centers of gravity, thrust or power, altitudes, and type of atmosphere and shall be used in the design of the airframe.

REQUIREMENT RATIONALE (A.3.2.7)

Speeds are one of the more visible operational needs. They influence the structural capability required in the airframe in many ways, including external local pressures and temperatures. Not only is this requirement needed, but close attention must be paid to its development and application.

REQUIREMENT GUIDANCE (A.3.2.7)

The speeds defined in the subparagraphs are to be based on the operational capability and margins of safety of flight required of the air vehicle. These speeds may be definitions, ratios of other speeds, functions of altitude, or combinations thereof. It may be desirable to present the airspeed requirements in a figure of equivalent airspeeds, calibrated airspeeds, Mach number, or a combination of these airspeeds versus altitude. Airspeeds and ground speeds should be in knots and identified as to the system's correct units of indicated (IAS), calibrated (CAS), or true (TAS) with the exception of sink speed and gust speeds which are in feet per second. For modification programs, use applicable technical order speeds with changes as required by the new usage. Airframe development and operating costs increase, often substantially, with increased maximum equivalent speed.

REQUIREMENT LESSONS LEARNED (A.3.2.7)

With the onset of new powerful engines, it appears that the speed criteria must be thoroughly evaluated. Trade studies need to be conducted to determine the most applicable and effective speeds and their usage.

A.3.2.7.1 Level flight maximum speed, V_H.

The level flight maximum speeds shall be the maximum authorized continuous level flight speeds required and otherwise attainable by the air vehicle.

REQUIREMENT RATIONALE (A.3.2.7.1)

The maximum level flight speed is one of the key speeds for defining the right side of the operational flight envelope (speed vs altitude) and the speed from which other speeds are usually derived, for example the limit speeds.

REQUIREMENT GUIDANCE (A.3.2.7.1)

The resultant speed-altitude envelopes are dependent, first, upon the usage requirements of the air vehicle and, secondly, as fall out capability of the power available and airframe. In many cases the aircraft will have a capability to exceed the maximum level flight speed derived from the operational requirements. This means a choice of which speed to establish for V_H is usually necessary. In making this choice the following should be considered:

a. The airframe is a significant portion of the aircraft cost to develop and to produce.

b. It has been the tradition and, therefore, the future expectation that operational requirements defined after completion of development be accommodated by the airframe without major changes in production cost.

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c. Retrofit of upgraded engines into airframes without major modifications has also been a tradition and therefore is an expected option for future designs.

d. The operator will develop an employment doctrine to utilize all the capability of the design. This leads to the conclusion that the design of the airframe must have growth potential and cannot be the limiting factor in the system growth potential. Therefore, the selection of V_H must be biased toward a value in excess of the stated need at the start of Full Scale Development and in favor of what the technology available will be expected to deliver during the planned service life. The one limiting factor that has been accepted in the past and can be expected to be acceptable in the future is the capability of the material system selected for the airframe. The selection of V_H should not be so excessive as to redefine the material system derived as meeting the operators' needs as stated for FSD.

REQUIREMENT LESSONS LEARNED (A.3.2.7.1)

There are many aerodynamic configurations possible for an aircraft with a variable sweep wing. Maximum attainable speed at different sweep configurations can easily exceed operational speed requirements. For a swing wing bomber the level flight maximum speed varied with wing sweep position and was based on speeds required to perform specified design missions. Mission requirements were obtained from the concept of employment issued by the using command.

A.3.2.7.2 Dive speed, VD. (______)

The dive speeds shall be the maximum authorized dive speeds necessary to perform the required missions and are __________________.

REQUIREMENT RATIONALE (A.3.2.7.2)

This speed is highly dependent upon the usage requirements of the air vehicle and to some extent will establish the attainable structural capability of the airframe.

REQUIREMENT GUIDANCE (A.3.2.7.2)

This requirement is to reflect intentional diving of the air vehicle. The definition needs to include initiation altitudes and speeds, flight path angles, engine power settings, deceleration device settings, recovery load factors and altitudes, and other factors pertinent to the requirement.

REQUIREMENT LESSONS LEARNED (A.3.2.7.2)

If the user cannot use a higher speed ground attack air vehicle, that is, the target cannot be identified and attacked within the time of one pass, a lower dive speed may be opted for by the user.

3.2.7.3 Limit speed, V_L.
The limit speeds shall be the maximum speeds of the air vehicle and are ____________.

REQUIREMENT RATIONALE (A.3.2.7.3)

The limit speed capability required of the airframe, when defined, provides engineering values for development tasks, the baseline against which to verify by analyses and tests that these speeds can be achieved, and that the structural integrity of the airframe is satisfactory when the air vehicle is flown at these speeds.

REQUIREMENT GUIDANCE (A.3.2.7.3)

These speeds will probably be the driving factor in establishing the strength and rigidity levels and materials and workmanship required in the airframe. This requirement is tempered only by

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the maximum capabilities of the other systems of the air vehicle. A suggested completion of the requirements is attained after an upset from continuous level flight for twenty seconds in a seven degree dive with no configuration, thrust, or power changes and a limit load factor pull-out or the dive speeds of 3.2.7.2 plus a ten percent speed margin, whichever is greater.

REQUIREMENT LESSONS LEARNED (A.3.2.7.3)

The limit speed dynamic pressure for an air to air fighter for the basic mission configuration is 1700 psf up to the altitude at which the dynamic pressure corresponds to a limit speed Mach number of 2.0.

The intent of a margin between V_H and V_L was to provide a practical protection for inadvertent transient excursion not exceeding one minute in duration. For a swing wing bomber this margin was established as a delta of $M = 0.1$ above V_H. This margin was applied to the aft sweep configuration only. For all other wing sweeps $V_L = V_H$.

A.3.2.7.4 Maneuver speed, VA. (_____)

The maneuver speeds shall be the speeds authorized for full maneuvering load factor capability of 3.2.9.1 and are ______________________.

REQUIREMENT RATIONALE (A.3.2.7.4)

Such a speed requirement may be needed to assure that the airframe structure has the maneuvering capability desired. The air loads may be distributed differently than level flight air loads thus effecting the structure directly.

REQUIREMENT GUIDANCE (A.3.2.7.4)

This speed requirement, in conjunction with 3.2.8.2 maneuver altitude, is to reflect the maneuvering capability required of the air vehicle.

REQUIREMENT LESSONS LEARNED (A.3.2.7.4)

A.3.2.7.5 Takeoff, approach, and landing limit speeds, V_{LF}.

The takeoff, approach, and landing limit speeds shall be the maximum authorized speeds associated with the operation of the landing gear and other devices for and during takeoff and landing operations. These speeds shall be high enough to provide the crew ample time to operate and control the devices with only nominal attitude and trim changes of the air vehicle flight and propulsion control systems. These speeds are ___________.

REQUIREMENT RATIONALE (A.3.2.7.5)

These speed requirements are necessary to assure adequate operational capability exists for the air vehicle to satisfactorily operate out of and into service airports and bases.

REQUIREMENT GUIDANCE (A.3.2.7.5)

The landing, approach, and takeoff limit speeds should be sufficient to allow operation of the air vehicle safely within these phases and to safely transition into and out of these phases. Some air vehicles may require only one speed for all of these phases, whereas, others may require several. An appropriate limit speed may need to be established for the operable speed range required of airframe components, for example, landing gear, slats, and flaps. These speeds must be relevant to the operations and operating crew efforts necessary to safely fly the air vehicle. Consideration must be given to such factors as the time required to extend or retract/close the high lift devices and landing gear when establishing V_{LF}. Safe transition

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between phases entails, in part, maintaining adequate margins above the 1.0g stall speeds and minimum control speeds. Consideration should also be given to maintaining sufficient margin above normal operating speeds to allow for pilot inaction. The importance of allowing for pilot inaction is largely a function of the acceleration and deceleration capability of the aircraft as the normal operating speed varies. The effect of altitudes higher than the maximum ground altitude at 3.2.8 should be considered to assure flight in these configurations will be adequate for operations to train flight crews.

REQUIREMENT LESSONS LEARNED (A.3.2.7.5)

A swing wing bomber landing, approach, and take off speeds for the landing gear and high lift devices were chosen to be compatible with expected operational capabilities and procedures. Speed varied as a function of flap extension and was based on maintaining a constant flap loading from 30 to 100 percent flap deflection. Maximum speed was derived using maximum airplane acceleration after a take off at 1.1 times stall speed, followed by a 6-second delay until initiation of flap retraction and a subsequent 20-second retraction time.

A.3.2.7.6 Lift-off limit speeds, V_{LO}.

The lift-off limit speeds shall be the maximum authorized and necessary ground speeds for the takeoff operations and are ___________.

REQUIREMENT RATIONALE (A.3.2.7.6)

When the airframe is in the takeoff configuration, this speed requirement is of particular importance in defining the maximum ground speed for establishing landing gear wheel and other aircraft characteristics.

REQUIREMENT GUIDANCE (A.3.2.7.6)

This speed is the maximum ground speed with any landing gear tire in contact with the ground during takeoff, including those takeoffs at maximum ground altitude in a hot atmosphere for any required mission using normal techniques for rotation and holding of pitch attitude.

REQUIREMENT LESSONS LEARNED (A.3.2.7.6)

A.3.2.7.7 Touch-down limit speeds, V_{TD}.

The touch-down limit speeds shall be the maximum authorized and necessary ground contact speeds for the landing operations and are __________.

REQUIREMENT RATIONALE (A.3.2.7.7)

The touch-down speed greatly influences the landing gear loads resulting from landing impact, particularly the spin-up and spring-back loads. The impact loads also are transmitted to the airframe and can result in significant dynamic loads, particularly affecting those items mounted on the extremities of the airframe, for example, external stores, control surfaces, etc.

REQUIREMENT GUIDANCE (A.3.2.7.7)

This speed is the maximum ground speed with any landing gear tire in contact with the ground during landing, including those landings at maximum ground altitude in a hot atmosphere. This also applies for a one go-around abort immediately after lift-off of any required mission, using normal techniques for holding of final approach pitch attitude and no pilot induced flare.

REQUIREMENT LESSONS LEARNED (A.3.2.7.7)

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A.3.2.7.8 Taxi limit speeds, V_T.

The taxi limit speeds shall be the maximum authorized and necessary ground speeds for ground operations on taxiways and ramps and are __________.

REQUIREMENT RATIONALE (A.3.2.7.8)

The airframe can experience significant ground induced dynamic loads which are a function of taxi speed. This speed requirement must be stated clearly so as to not compromise the structure if the flight crew cannot discern this speed limit and may inadvertently overload the structure. Further, if the speed is arbitrarily set too high, the airframe will have extra weight which will be carried throughout its life.

REQUIREMENT GUIDANCE (A.3.2.7.8)

Large and heavy air vehicles may require two taxi limit speeds, one for ramps and one for taxiways. However, the two speeds must be identifiable and discernible to the operating crew so they can operate safely within these speeds. The taxi limit speeds must be compatible with the intended operational usage of the air vehicle and the ability of the operating crew to recognize the taxi limit speeds and keep the air vehicle ground speeds below them on ramps and taxiways. Ramp speed may be expressed in terms of a man walking at tip of wing (4-8 knots) and taxiing on ramps (30-40 knots). Operations using high speed taxi turn-offs will require much higher taxi speeds to be established.

REQUIREMENT LESSONS LEARNED (A.3.2.7.8)

The residual thrust at idle power setting for a high thrust to weight fighter resulted in taxi speeds up to 60 knots to avoid excess brake wear and maintenance. This required the canopy to be closed, since the canopy open speed did not cover this operating concept.

A.3.2.7.9 Gust limit speeds, V_G.

The gust limit speeds shall be the maximum authorized speeds for continued operation in turbulent air and are __________.

REQUIREMENT RATIONALE (A.3.2.7.9)

In general, for a given gust velocity, the loads induced in the airframe are a linear function of the speed of the air vehicle. Further, at high speed, gust induced structural loads may be considerably higher than maneuver loads. Turbulence loads that the air vehicle will be subjected to can be controlled to some degree by the flight crew selecting speed and using slow down techniques. Identification of the maximum rough air speed and how it can be achieved through speed control is operationally essential. Therefore, this positive control action needs to be taken advantage of through this speed requirement.

REQUIREMENT GUIDANCE (A.3.2.7.9)

This speed must be compatible with the intended usage of the air vehicle as well as the ability of the operating crew to identify turbulent air. Further, if this speed is to be less than the limit speed of 3.2.7.3, the ability of and the time it takes the air vehicle to decelerate to this speed must be considered in establishing this speed.

REQUIREMENT LESSONS LEARNED (A.3.2.7.9)

The V_G airspeed has historically been associated with the 66 fps discrete gust encounters as a means of quantifying severe turbulence. V_G must be neither too high (high loads) or too low (stall upset). $\sqrt{n_g}\,V_{S1}$ or the intersection of C_{NAMAX} and the rough air (66 fps) gust line have

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been widely used in the past and may still be satisfactory. However, careful consideration of the need for a higher V_G should be given if the calculated speed results in frequent exceedance of the stall angle of attack particularly of the higher operating altitudes. All large swept wing aircraft have had upsets at high altitudes from control problems as stall is approached in turbulence.

A.3.2.7.10 Maneuver stalling speeds, V_{S1}.

The maneuver stalling speeds shall be the minimum level flight speeds with flaps retracted.

REQUIREMENT RATIONALE (A.3.2.7.10)

This speed requirement is needed to establish the gust limit speeds which will be authorized for continued operation in turbulent air.

REQUIREMENT GUIDANCE (A.3.2.7.10)

This speed must be carefully established to assure that the gust limit speed authorized for continued operation in turbulent air has adequate stability and stall margins.

REQUIREMENT LESSONS LEARNED (A.3.2.7.10)

A.3.2.7.11 Landing stalling speeds V_{SL}.

The landing stalling speeds shall be the minimum level flight speeds in the landing configuration with zero thrust.

REQUIREMENT RATIONALE (A.3.2.7.11)

This speed requirement is needed to establish the minimum level flight speed in the landing configuration and to define the left side of the operational flight envelope (speed vs altitude).

REQUIREMENT GUIDANCE (A.3.2.7.11)

The stalling speeds shall be sufficient to allow operation of the air vehicle safely within the landing phases and to safely transition into and out of the landing phases. Some air vehicles may require only one speed for all of these phases, whereas, others may require several. These speeds must be relevant to the operations and operating crew efforts necessary to safely fly the air vehicle. Safe transition between phases entails, in part, maintaining adequate margins for control.

REQUIREMENT LESSONS LEARNED (A.3.2.7.11)

A.3.2.7.12 System failure limit speeds, V_{SF}.

The maximum speeds for flight after detectable system failures of 3.2.22 from which recovery is expected shall be __________.

REQUIREMENT RATIONALE (A.3.2.7.12)

This speed requirement is needed to provide the flight crew with sufficient confidence to continue flight after an in-flight failure has occurred and thus allow for recovery of both the crew and air vehicle with minimum injury and damage thereto.

REQUIREMENT GUIDANCE (A.3.2.7.12)

It may be desirable to establish two system failure limit speeds, one for flight involving usage of the landing gear and high lift devices, and one for other configurations and flight conditions. These speeds must be high enough to assure continued safe and controlled flight including

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performance of maximum system failure load factor maneuvers after any in-flight system failure from which recovery is expected, but not so high as to induce a large weight penalty.

REQUIREMENT LESSONS LEARNED (A.3.2.7.12)

A.3.2.7.13 Shipboard recovery speed, VTDC. (____)

This shall be the maximum deck touch-down speed for determining recovery bulletin limits based on the Carrier Landing Design Gross Weight, critical c.g. position and store loadings authorized for bring-back. This value used to determine structural landing criteria shall be based on design performance requirements and tropical day temperature.

REQUIREMENT RATIONALE (A.3.2.7.13)

The mean shipboard recovery speed influences the determination of engaging speed and sink rate.

REQUIREMENT GUIDANCE (A.3.2.7.13)

This speed is based on the defined on-speed angle of attack which meets the performance requirements for carrier operations times a factor of 1.05. The on-speed angle of attack and corresponding approach speed (VPA vs. weight) will become a part of the NATOPS (Naval Air Training and Operating Procedures Standardization) and the VTD=1.05 VPA will be listed in the ship-board recovery bulletin for the purpose of wind over deck determination.

REQUIREMENT LESSONS LEARNED (A.3.2.7.13)

The analytical determination of approach speed and its shorebased validation during flight test has been shown to be statistically lower than the value measured at the ship during normal operations, thus the correction factor of 1.05 is used to reflect the observed touch down speed.

A.3.2.7.14 Shipboard engaging speed, VE. (____)

For structural airframe design this shall be equal to the "Shipboard Recovery Speed" less the average wind over deck plus a 3.1 sigma (P_o = .001) on engaging speed derived from aircraft survey data of similar class aircraft.

REQUIREMENT RATIONALE (A.3.2.7.14)

The mean engaging speed is used in the determination of sink rate and the maximum engaging speed is used in the determination of the arresting hook design loads. Engaging speed is one of the eight multivariate landing parameters.

REQUIREMENT GUIDANCE (A.3.2.7.14)

The mean engaging speed is equal to the shipboard touch down speed (VTDC) minus 20 knots wind over deck. The standard deviation of engaging speed is 5.0 knots for carrier aircraft and 8.0 knots for trainers and STOL aircraft. The range of maximum and minimum values of engaging speed is equal to the mean value plus/minus 3.1 standard deviations.

REQUIREMENT LESSONS LEARNED (A.3.2.7.14)

The allowable engaging speed is both a limiting parameter for the airframe and its operational capability and is also a limiting value of the shipboard recovery equipment.

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A.4.2.7.15 Shipboard launch end speed, VC. (____)

This shall be the minimum launch end speed required not to exceed ________ feet of sink over the bow (summation of ship speed, natural winds, and catapult end speed).

REQUIREMENT RATIONALE (A.3.2.7.15)

This parameter sets the lower limit for catapult tow force.

REQUIREMENT GUIDANCE (A.3.2.7.15)

The operational value of catapult end speed is equal to the minimum value plus 15 knots.

REQUIREMENT LESSONS LEARNED (A.3.2.7.15)

3.2.7.16 Maximum brake speed, V_{HD}. (____)

This shall be the maximum allowable speed at which the arresting hook may be lowered during carrier operations and is ___________.

REQUIREMENT RATIONALE (A.3.2.7.16)

This speed will determine the arresting hook extend system design load requirements.

REQUIREMENT GUIDANCE (A.3.2.7.16)

During carrier operations, the arresting hook extend loads are based on the airspeed while the aircraft is transitioning through the break at 400 knots or greater.

REQUIREMENT LESSONS LEARNED (A.3.2.7.16)

Landing gear extend and retract design speeds are based on speeds in the high lift take-off and landing configuration and are too low of a value for carrier operation where the aircraft is transitioning through the break in the cloean or up-away configuration. In the break, the pilot is required to extend the hook and perform a tight turn simultaneously while in the cloean configuration. Also if a bolter occurs, the pilot does not want to raise the hook but to keep it in the trail position as he goes around.

A.3.2.7.17 Emergency jettison speeds. (____)

The emergency jettison speeds of all stores or suspension equipment shall be the maximum authorized speeds necessary for safe release and are _________.

REQUIREMENT RATIONALE (A.3.2.7.17)

This speed requirement is needed to establish the maximum speed authorized for safe simultaneous release of all stores or suspension equipment in an emergency situation.

REQUIREMENT GUIDANCE (A.3.2.7.17)

Define the emergency jettison speed requirements. Since high loads may be induced into the airframe during simultaneous release of stores, this speed should be carefully established. The emergency jettison speeds should be compatible with the intended operational usage of the air vehicle and the ability of the operating crew to maintain control of the aircraft.

REQUIREMENT LESSONS LEARNED (A.3.2.7.17)

A.3.2.7.18 Selective jettison speeds. (____)

The selective jettison speeds of all stores or suspension equipment no longer required for performance of the missions and are _________.

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REQUIREMENT RATIONALE (A.3.2.7.18)

This speed requirement is needed to establish the maximum speed authorized for selective release of stores or suspension equipment in an unarmed or unguided condition.

REQUIREMENT GUIDANCE (A.3.2.7.18)

Define the selective jettison speed requirements. Since high loads may be induced into the airframe during selective release of stores, this speed should be carefully established. The selective jettison speeds should be compatible with the intended operational usage of the air vehicle and the ability of the operating crew to maintain control of the aircraft. In general, the selective jettison speeds will be applicable to jettison of one store type at a time.

REQUIREMENT LESSONS LEARNED (A.3.2.7.18)

A.3.2.7.19 Store employment speeds. (____)

The release speeds for store employment shall be the maximum authorized speeds necessary to perform the required missions and are _________.

REQUIREMENT RATIONALE (A.3.2.7.19)

This speed requirement is needed to establish the maximum speed authorized for release of stores for their intended purposes in an armed or guided condition.

REQUIREMENT GUIDANCE (A.3.2.7.19)

Define the store employment speed requirements. Since high loads may be induced into the airframe during release of stores, this speed should be carefully established. The store employment speeds should be compatible with the intended operational usage of the air vehicle and the ability of the operating crew to maintain control of the aircraft. In general, the store employment speeds will be applicable to release of one store type at a time.

REQUIREMENT LESSONS LEARNED (A.3.2.7.19)

A.3.2.7.20 Other speeds.

Other speeds applicable to specified uses are __________________.

REQUIREMENT RATIONALE (A.3.2.7.20)

Not all required speeds can be identified in the general specification, therefore other speed requirements are necessary to allow for identifying speeds related to other useful aircraft configurations.

REQUIREMENT GUIDANCE (A.3.2.7.20)

List and define other speeds as necessary and applicable to the air vehicle and its intended usage.

REQUIREMENT LESSONS LEARNED (A.3.2.7.20)

With a petal door design, a large transport has a 200 knots calibrated airspeed (KCAS) airdrop configuration limit speed. However, there is a 180 KCAS airdrop limit speed due to the differential pressure created on the petal doors during the extraction of the cargo.

There have been several instances of accidents caused by the crew deploying high lift devices at speed above the extended use speed of the device, so care should be exercised in establishing the extended usage speed of devices, their speed limitations and including the limits in applicable documents.

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One air-to-air fighter has leading and trailing edge maneuvering flaps that can be used during combat. Such maneuvering flap speed, which are a function of leading edge and trailing edge flap deflection angles, can be defined here or in 3.2.7.4. Single engine out speeds, if applicable, may be listed here. Cargo aircraft that perform airdrop missions may have airdrop configuration limit speeds for personnel and cargo airdrop.

A.4.2.7 Speeds.

The speeds of 3.2.7 shall be shown to be attainable by the air vehicle by analyses and tests. The following speeds shall be shown to be attainable by the air vehicle by the indicated analyses/tests: ___________________.

VERIFICATION RATIONALE (A.4.2.7)

Not all speeds are critical and may be verified by an appropriate analysis, however, the speeds most significant to the structural integrity of airframe, particularly the high speeds, need to be verified by test.

VERIFICATION GUIDANCE (A.4.2.7)

Identify and list those speeds of 3.2.7 which are to be verified by analyses, those to be verified by tests, and those to be verified by both analyses and tests.

VERIFICATION LESSONS LEARNED (A.4.2.7)

A.3.2.8 Altitudes.

The following altitudes and any attainable lesser altitudes are applicable for ground and flight use of the air vehicle considering required and expected to be encountered combinations of configurations, gross weights, centers of gravity, thrust or power, speeds, type of atmosphere, and the usage of 3.2.14 and shall be used in the design of the airframe.

A.3.2.8.1 Maximum flight altitude.

The maximum flight altitude shall be the maximum altitude authorized and necessary for flight operations.

A.3.2.8.2 Maneuver altitude. (______)

The maneuver altitude shall be the maximum altitude authorized and necessary for full load factor maneuvering capability of 3.2.9.1.

A.3.2.8.3 Maximum ground altitude.

The maximum ground altitudes shall be the maximum altitudes authorized and necessary for ground operations.

REQUIREMENT RATIONALE (A.3.2.8 through A.3.2.8.3)

Altitude requirements are needed because density and temperature effects associated with altitude variations also effect the loads, etc., the structure is subjected to during its usage and hence the structural integrity of the airframe is effected.

REQUIREMENT GUIDANCE (A.3.2.8 through A.3.2.8.3)

For modification programs, the appropriate altitudes from applicable technical orders with changes as necessary to be compatible with the air vehicle as modified and its new usage are

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applicable. For other programs, altitudes consistent with the intended usage of the air vehicle are applicable. The maximum flight altitude includes the highest pressure altitude at which the air vehicle must be capable of flying. The maneuver altitude includes the highest pressure altitude, based on maneuvering capability required of the air vehicle, at which the air vehicle must be capable of full load factor maneuvers. The maximum ground altitude includes the highest ground elevation at which the air vehicle must be capable of operating regarding ground handling, takeoffs, and landings.

REQUIREMENT LESSONS LEARNED (A.3.2.8 through A.3.2.8.3)

A.4.2.8 Altitudes.

The altitudes of 3.2.8 shall be demonstrated to be attainable by the air vehicle by analyses and tests. The following altitudes shall be shown to be attainable by the air vehicle by the indicated analyses/tests: __________________.

VERIFICATION RATIONALE (A.4.2.8)

While maneuvering flight may not be attainable at all desired altitudes by the flight test vehicles, engine changes may be incorporated in the future that will make it possible.

VERIFICATION GUIDANCE (A.4.2.8)

Identify and list those altitudes of 3.2.8 which are to be verified by analyses, those to be verified by tests, and those to be verified by both analyses and tests.

VERIFICATION LESSONS LEARNED (A.4.2.8)

A.3.2.9 Flight load factors.

The following flight load factors shall be the maximum and minimum load factors authorized for flight use and shall be used in the design of the airframe.

A.3.2.9.1 Basic flight design gross weight load factors.

The normal flight weight maximum and minimum load factors are _______________.

A.3.2.9.2 Maximum flight weight load factors.

The maximum flight weight maximum and minimum load factors are ________________.

A.3.2.9.3 Takeoff, approach, and landing load factors.

The takeoff, approach, and landing maximum and minimum load factors are ______________.

A.3.2.9.4 High drag load factors.

Load factors to be considered in the high drag configuration are _____________.

A.3.2.9.5 Air vehicle load factors after detectable system failures.

After recovery from any in-flight failure, as defined in 3.2.22, the allowable load factors for return to base shall be those which result in loads that do not exceed __________ of structural design limit loads.

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A.3.2.9.6 Other flight load factors. (_______)

Other load factors applicable to specified flight uses are: _______________.

REQUIREMENT RATIONALE (A.3.2.9 through A.3.2.9.6)

Definition of flight load factors required for operational use of the airframe is probably the one requirement of most significance to setting the structural capability of the airframe. This requirement is needed and must be carefully addressed throughout the program to assure that full operational maneuver capability of the airframe is achieved.

REQUIREMENT GUIDANCE (A.3.2.9 through A.3.2.9.6)

For modification programs, use the appropriate load factors from applicable Air Force Technical Orders (T.O.)/Navy Aircraft Technical Operations Procedures (NATOPs) with changes as necessary to be compatible with the modified air vehicle and its new usage. For other programs, define or select load factors consistent with the intended usage of the air vehicle. In each subparagraph, include the maximum and minimum load factors for symmetric, asymmetric, and lateral maneuvers.

Normal flight weight load factors are the highest and lowest load factors reasonably expected to be encountered by any air vehicle of the fleet performing any of the maneuvers of required operations and missions.

Maximum flight weight load factors should be of sufficient magnitude to allow the air vehicle to maneuver safely at high gross weights, such as immediately after takeoff or aerial refueling. The product of normal and maximum flight weights times their associated load factors should be equal, if practical.

Landing, approach, and takeoff load factors should be compatible with air vehicle high lift configurations and the maneuvers required to safely operate the air vehicle during these flight phases.

High drag load factors should be compatible with air vehicle high drag configuration(s) and all maneuvers of required operations and missions to safely operate in that configuration.

Allowable load factor, after recovery from an in-flight failure as defined in 3.2.22, should be sufficient for minimum navigation and landing maneuvers.

For other flight load factors, identify and present other load factors as necessary to quantify the full operational maneuver capability required of the air vehicle. In general, load factor selection is a major concern, not only to those who are responsible for determination of adequate strength levels, but for those who must adapt these aircraft to continually varying operational requirements. During load factor selection, the following items must be considered:

a. Mission and flying techniques employed to execute the required mission.

b. Weapon types and possible delivery methods.

c. Weight and power plant growth anticipated.

d. Maximum speed and time spent at maximum speed.

e. Utilization of external stores and external fuel tanks.

f. Training.

g. Past experience with similar types of aircraft, mission, etc.

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Load factor definitions must include appropriate ranges for symmetrical, roll, and directional maneuvers in each configuration. Consideration should be given to use of a reduced load factor range at speeds above V_H.

REQUIREMENT LESSONS LEARNED (A.3.2.9 through A.3.2.9.6)

The load factor requirements established in 1949 for fighter aircraft are as follows:

Class I	limit load factor +8.67 and -4.0.
Class II	limit maneuver load factor +7.33 and -3.0.
Class III	unspecified, but intended for +5.33 and -3.0 for specific high altitude types.

Class I fighters were known as low altitude, high strength, general purpose types designed to limit load factors of +8.67 and -4.0 at combat weight. Aircraft of this Class were designed for high maneuverability and high speeds at low altitudes. Consequently, they were limited to a relatively short radius of action. This type was suited for close air support work at shorter ranges. These airplanes were not adaptable to high altitude fighting. They could be satisfactorily used at intermediate ranges and altitudes by substitution of fuel tanks for weapons. These aircraft were rugged and well suited for training.

Class II fighters were long range, intermediate altitude types of medium strength. They were used for escort work, interdiction, or air superiority at longer ranges. They were designed to +7.33 and -3.0 at combat weight. They were adequate for limited use at short range and high altitude if fuel load was reduced. They could be used for close air support at lower load factors by the replacement of fuel with weapons.

Class III fighters were high altitude interceptors low load factor (+5.33 to -3.0) capability. This allowed minimum structural weight and maximum high altitude performance. They were adequate for limited use at intermediate altitudes but were inadequate for general air superiority or close air support missions.

These fighter classes were established to provide sufficient strength and rigidity for a primary. This strict tactical definition minimized multi-mission capability.

In the 1960s, the MIL-A-8860 series specifications established a limit loads factor of 7.33g for fighters with the asymmetric limit load factor being 80% of the symmetric value. During the Lightweight Fighter program in the mid-1970s, it was found that the design symmetric load factor could be increased from 7.33g to 9g with very little weight penalty. However, the design asymmetric load factor remained at 80% of 7.33g (5.86g). As the program matured, trade studies were conducted to investigate the impact of increasing the design asymmetric load factor to 80% of 9g (7.2g). Results indicated that the weight penalty for increasing the asymmetric limit was substantially greater than that for the increased symmetric limit.

For a swing wing low level, terrain following bomber, it was found to be advantageous to require higher load factors for swept configurations than for wings extended. This allowed terrain following and fly-up capability with minimum airfield configuration penalties. A ratio of terrain following to fly-up limit load factor of 0.8 was adequate.

Cargo aircraft typically have symmetrical limit load factor ranges of +3.0 to -1.0 for assault category and +2.5 to -1.0 for transport category aircraft at normal flight weight and at speeds up to V_H. At V_L the lower value is reduced to 0.0. The asymmetrical load factor range is typically 1.0g to 0.8 times the symmetrical load factor range. For directional maneuvers the load factor is 1.0.

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A.4.2.9 Flight load factors.

The load factors of 3.2.9 shall be demonstrated to be attainable by the air vehicle by analyses and tests.

VERIFICATION RATIONALE (A.4.2.9)

This requirement verifies that the operational maneuver capability of the airframe exists. The performance and structural integrity of the airframe must be verified and shown capable of performing the maneuvers to the required load factors.

VERIFICATION GUIDANCE (A.4.2.9)

The load factors of 3.2.9 are to be demonstrated to be attainable by analyses and tests.

VERIFICATION LESSONS LEARNED (A.4.2.9)

A.3.2.10 Land based and ship based aircraft ground loading parameters.

The airframe shall have sufficient structural integrity for the air vehicle to take-off, catapult, land, arrest, and operate on the ground or ship under the appropriate conditions of 3.4.2 and the parameters defined here-in, in attainable combinations, considering the required and expected combinations of the applicable parameters of 3.2 and 3.4. Lesser values of the following parameters are applicable in determining attainable combinations.

REQUIREMENT RATIONALE (A.3.2.10)

Ground loading parameters need to be established realistically for the air vehicle to assure that adequate structural integrity exists in the airframe for all operational usage.

REQUIREMENT GUIDANCE (A.3.2.10)

Ground loads depend on the weight of the aircraft, the landing and taxi gear arrangements, and how the aircraft will be maneuvered on the ground. This section specifies the external conditions which constitute forcing functions to the air vehicle and the maximum rates of sink at ground contact in landing which specifies the energy to be absorbed due to the aircraft kinetic energy at landing.

REQUIREMENT LESSONS LEARNED (A.3.2.10)

A.3.2.10.1 Landing sink speeds.

The maximum landing touchdown vertical sink speeds of the air vehicle center of mass to be used in the design of the airframe and landing gear shall not be less than:

a. Landplane landing design gross weight: ___________________.

b. Ship based landing design gross weight (_____):___________________.

c. Maximum land based landing weight: _________________.

REQUIREMENT RATIONALE (A.3.2.10.1)

The landing sink speed requirement is needed to assure that adequate energy absorption capability exists in the landing gear shock absorbers and arresting hook damper (to preclude hook bounce), and that the rest of the airframe is able to withstand the dynamic loads resulting from the landing impact.

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REQUIREMENT GUIDANCE (A.3.2.10.1)

Choose the limit sink speed compatible with the air vehicle's intended usage and the repeated load sources sink speeds of 3.2.14.2. The sink speeds of 3.2.14.2 are based on cumulative occurrences at the lower or mid-band value. Thus, the landplane landing weight sink speed should be the associated upper-band value. The maximum landing weight sink speed should be 60% of the landplane landing weight sink speed value. However, it should be no less than that sink speed resulting from the air vehicle landing at its maximum landing weight and associated maximum landing touchdown velocity without flare reducing the sink speed from a two degree glide slope approach.

For Navy aircraft, the design mean sink rate is a function of the ship Frensol Lens setting, the approach speed of the aircraft, size and characteristics of the ship, and the sea state conditions in which operations are allowed. Based on carrier surveys the mean sink speed is equal to 0.128 times the mean engaging speed (in knots); and the standard deviation of sink rate is equal to 0.015 times engaging speed plus 1.667 fps. Sink rate is one of the eight multivariate parameters in which the maximum/minimum values equal the mean plus or minus 3.1 standard deviations.

REQUIREMENT LESSONS LEARNED (A.3.2.10.1)

A.3.2.10.2 Crosswind landings.

The crosswinds at take-off and landing shall be those components of surface winds perpendicular to the runway centerline or ship landing reference centerline. The landing gear loads resulting from crosswind operations shall be ____________________.

REQUIREMENT RATIONALE (A.3.2.10.2)

Crosswind landings cannot be avoided throughout the life of the air vehicle. Therefore, this requirement is needed to assure adequate strength exists in the airframe for either field or shipboard operations.

REQUIREMENT GUIDANCE (A.3.2.10.2)

Most airports are laid-out with the runways in line with the prevailing wind. However, it is not uncommon to have winds of reasonable magnitudes blowing from any direction. Crosswind and drift landings can result in main gear side loads up to 80% of the vertical reaction for the inboard acting load and 60% of the vertical reaction for the outboard acting load. The vertical reaction is generally considered to be 50% of the maximum vertical reaction from two point and level symmetrical landings. The side loads and vertical reactions (with zero drag load) should act simultaneously at the ground with these loads being resisted by the aircraft inertia. Alternatively, a dynamic analysis of shipboard and field landings for 90° crosswinds of 30 kts may be accomplished for typical landing techniques (e.g. crabbed, tail-down top rudder).

REQUIREMENT LESSONS LEARNED (A.3.2.10.2)

A.3.2.10.3 Land-based landing roll, yaw, pitch attitudes, and sink speed.

The landing touchdown roll, yaw, pitch attitude, and sink speed combinations shall be based on a joint probability distribution and within an ellipsoid with axes of roll, yaw, and pitch. The extremes on these axes are:

a. Roll angle. Plus _________ and minus _____________.

b. Yaw angle. Plus _________ and minus _____________.

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c. Pitch angle. Mean plus _________ and minus _____________.

d. Sink speed. Mean plus __________ and minus ___________.

REQUIREMENT RATIONALE (A.3.2.10.3)

This requirement is needed to assure that adequate structural integrity exists in the airframe for all types of landings of which the air vehicle may be subjected.

REQUIREMENT GUIDANCE (A.3.2.10.3)

The roll angles (plus and minus) should be the same and no less than that roll angle needed to maintain the longitudinal axis of the air vehicle in line with the runway centerline when landing in a maximum crosswind without ground effect, flare, or pilot alleviation prior to touchdown. The yaw angle (plus and minus) should be equal and no less than that yaw angle needed to maintain a flight path in line with the runway centerline when landing (wings level) in a maximum crosswind without ground effect, flare, or pilot alleviation prior to touchdown. The pitch angles (plus and minus), normally will not be equal. The positive angle should be the maximum angle attainable considering landing parameters, aerodynamics, tail bumper contact (or contact of other parts of the airframe), etc. The negative angle should be the minimum angle attainable considering landing parameters, aerodynamics, etc. Sink speeds associated with the above landing attitudes shall be combined to produce the landing conditions. For tricycle landing gear air vehicles, nose landing gear first landings should be considered only for training aircraft.

REQUIREMENT LESSONS LEARNED (A.3.2.10.3)

A.3.2.10.4 Taxi discrete bumps, dips, and obstructions.

The bumps and dips shall be of the _________ wave lengths, amplitudes, and shape.

a. Maximum ground weight, slow speeds up to: ____________.

b. Maximum ground weight, speeds at and above: ________________.

REQUIREMENT RATIONALE (A.3.2.10.4)

Requirements for discrete runway roughness parameters are needed to assure that adequate structural integrity exists in the airframe to resist the dynamic loads induced during taxi over all operational ground surfaces.

REQUIREMENT GUIDANCE (A.3.2.10.4)

The slow speed requirement must cover all surfaces, including parking areas, ramps, and taxiways, as well as the runway. The values on figure 4 should be used, choosing those curves applicable to the type surface to be operated on. The higher speed requirement needs cover only runways. The aircraft transition over bumps and dips should be such that the angle between the path of the aircraft and the lateral axis of the contour will be all angles up to 45 degrees. The values on figure 5 should be used, choosing those curves applicable to the type of surface to be operated on. Displaced runway/taxiway concrete slabs, hangar doorway rails, bomb damaged repaired runway profiles, etc. may also be included.

REQUIREMENT LESSONS LEARNED (A.3.2.10.4)

A.3.2.10.5 Jacking wind loading conditions.

The maximum combination of wind loading and air vehicle load factor conditions that shall be allowed during the jacking of the air vehicle are __________.

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REQUIREMENT RATIONALE (A.3.2.10.5)

This requirement defines the maximum wind loading conditions that will be assumed to exist in determining the total forces and loads acting on the air vehicle during jacking.

REQUIREMENT GUIDANCE (A.3.2.10.5)

The maximum wind loading conditions can be determined from weather records taken at military and civilian airfields. Specify the magnitude and direction of the winds relative to the longitudinal axis of the air vehicle.

REQUIREMENT LESSONS LEARNED (A.3.2.10.5)

A.3.2.10.6 Catapult takeoff. (_______)

a. Maximum catapult design gross weight _____________.

b. Maximum catapult weight _____________.

c. Primary catapult mission weight _____________.

d. Maximum N_X (rigid c.g.) ______________.

e. Maximum horizontal tow force ____________.

f. Repeatable release holdback bar load ___________.

REQUIREMENT RATIONALE (A.3.2.10.6)

This requirement defines the analysis requirement for the catapult run, dynamic loads determination used for airframe strength design, and for determining the shock environment of mass items.

REQUIREMENT GUIDANCE (A.3.2.10.6)

The catapulting loads, for all weights ranging from the primary mission to the maximum catapult weight as limited by the maximum N_X and maximum tow force, throughout the catapult run, and the required initial spotting shall be determined for all specified catapults and catapult forces. The engine thrust should be all values from zero to maximum. The effects of pretension loads, holdback release, and weight variations shall be included.

REQUIREMENT LESSONS LEARNED (A.3.2.10.6)

The results of holdback release and end of shuttle run cause large dynamic airframe response accelerations and inertia loads which effect equipment design, fuel slosh (fuel pressures), and external store responses. The catapults which determine maximum tow force may not be the catapult which causes maximum dynamic response, thus all combinations of CVS setting, launch weight, and catapult must be included in the analysis.

A.4.2.10 Land-based and ship-based aircraft ground loading parameters.

The air vehicle shall be shown capable of takeoff, landing, and operating under the conditions and parameters of 3.2.10 and 3.4.2 by analyses and tests.

VERIFICATION RATIONALE (A.4.2.10)

Verification that the airframe can achieve the required ground loading parameter of 3.2.10 is needed to assure that the air vehicle can satisfactorily operate on the ground.

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VERIFICATION GUIDANCE (A.4.2.10)

The ground loading parameters of 3.2.10 reflect required operational capability of the air vehicle. The capability of the airframe will be developed by other technical disciplines such as loads, strength, durability and damage tolerance, handling qualities, performance, etc. Most of the verification of these parameters can be achieved by coupling their verification with applicable verification requirements specified for other technical disciplines.

VERIFICATION LESSONS LEARNED (A.4.2.10)

A.3.2.11 Limit loads.

The limit loads, to be used in the design of elements of the airframe subject to deterministic design criteria, shall be the maximum and most critical combination of loads which can result from authorized ground and flight use of the air vehicle, including maintenance activity, the system failures of 3.2.22 from which recovery is expected, a lifetime of usage of 3.2.14, all loads whose frequency of occurrence is greater than or equal to __________ per flight. All loads resulting from the requirements of this specification are limit loads unless otherwise specified.

REQUIREMENT RATIONALE (A.3.2.11)

This requirement defines the load capability that the airframe must possess to achieve adequate structural safety and economic operation. Where such loads are the result of randomly occurring loads, the minimum frequency of occurrence of these loads must be defined. This insures the inclusion of loads which are of sufficient magnitude to size elements of the airframe and whose frequency of occurrence warrants their inclusion.

REQUIREMENT GUIDANCE (A.3.2.11)

Limit loads reflect the operational requirements. These loads establish the structural envelope which defines the capability of the airframe to resist loads experienced during flight within the flight manual and handbook limits and the loads experienced during and following the system failures of 3.2.22 from which recovery is expected.

The determination of the limit loads includes flight anywhere within the design flight envelope. This selection of limit loads should address all critical combinations of inertia, aerodynamic and mechanical forces, heat flux and the thermal strains resulting from the resulting temperature gradients, variations in payload, external configurations, types of missions, and fuel and its distributions. Conservative predictive and test methods should be used to determine these loads. When determining the loads, expected variations in the ability of the pilot or the flight control system to maintain flight within the established limits should be addressed. This is especially important when the performance capability of the air vehicle significantly exceeds the flight manual and handbook limits.

The selection of the critical limit loads needs to take into account the time dependency of the occurrence of the loads. For some aircraft, such as modern fighters, the maximum tail loads may occur at different times during the maneuver and not necessarily during the sustained portion of the maneuver. For airframe components subjected to significant heat flux, the critical design condition does not necessarily coincide with the occurrence of the maximum heat flux.

The selection of the minimum frequency of occurrence of loads, to be included in the determination of the limit loads, can be done by assessing frequency data for similar types of aircraft performing similar missions. This data can then be used in determining the rates at which loads are experienced which cause detrimental structural deformation for structure built

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using conventional structural design criteria. It is generally only necessary to include loads whose frequency of occurrence is greater than or equal to 1 x 10^{-7} per flight.

REQUIREMENT LESSONS LEARNED (A.3.2.11)

A.4.2.11 Limit loads.

The limit loads shall be verified by analyses and tests.

VERIFICATION RATIONALE (A.4.2.11)

Limit loads are loads to be expected in service. These loads must be verified to assure that the airframe usefulness is not degraded and limited during operational use of the air vehicle.

VERIFICATION GUIDANCE (A.4.2.11)

Each limit load or combination of limit loads is to be verified. These loads are to be verified analytically early in the program to provide as much confidence as practical that the verification testing will not uncover problems.

VERIFICATION LESSONS LEARNED (A.4.2.11)

The later in the program that unconservative limit loads are discovered, the larger the cost and schedule overruns that result.

A.3.2.12 Ultimate loads.

Ultimate loads not derived directly from ultimate load requirements of this specification shall be obtained by multiplying the limit loads by appropriate factors of uncertainty. These ultimate loads shall be used in the design of elements of the airframe subject to a deterministic design criteria. These factors of uncertainty and the circumstances where they are to be used are __________.

REQUIREMENT RATIONALE (A.3.2.12)

This requirement establishes the ultimate load capability that the airframe must possess to provide adequate structural integrity. The factors of uncertainty and the conditions and circumstances where these factors are used are defined so that the calculation of ultimate loads can be made. Historical service experience has shown that an acceptable level of risk of loss of aircraft due to structural failure can be attained if limit loads are multiplied by a factor of uncertainty (formerly known as a factor of safety) of 1.5.

REQUIREMENT GUIDANCE (A.3.2.12)

The selection of the factor of uncertainty, formerly called the factor of safety, should be made by assessing the factors that have been used on similar air vehicles performing similar missions. The value for manned aircraft has been 1.5. The value for unmanned aircraft has been 1.25, except that a factor of 1.5 has been used when a failure of the structure could result in injury to personnel or damage to or loss of the carriage and launch equipment. The 1.5 factor has been successfully used on metallic airframes using "A" and "B" material allowables, well understood analysis methods validated through appropriate testing, demonstrated fabrication methods, and correct maintenance and inspection procedures.

The selected value of the factor of uncertainty should be increased to account for above normal uncertainty in the design, analysis and fabrication methods, when the inspection methods have reduced accuracy or are limited by new materials and new fabrication methods, and where the usage of the air vehicle is significantly different. Similar considerations need to be made in the

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selection of the factor for unmanned aircraft. The use of reduced factors of uncertainty needs to be carefully defined and justified. In this case, consideration of the impact of the use of reduced factors on the safety, maintenance, performance, and structural life needs to be addressed. Such reductions should only be undertaken when a substantial positive benefit to the air vehicle is shown.

Where thermal loads are significant, factors of uncertainty to apply to the external or internal thermal loads should be specified. The selection of these factors should consider the following:

a. The nature of the thermal load - is it an externally generated load or is it internally generated as the result of the operation of vehicle equipment and systems?

b. The ability to accurately measure the magnitude of the thermal loads and the structural response in real time during flight and, if necessary, the ability to predict the future structural response based on the thermal load history that the air vehicle has experienced.

c. The ability to make real time changes in the flight conditions or the operation of vehicle systems to keep the thermal loads within acceptable limits.

d. The accuracy of the predictive methods used to determine the thermal loads used in the design of the airframe.

e. The accuracy of the predictive methods used to determine the structural response of the airframe to the input thermal loads.

f. The criticality of the failure of the thermally loaded structure, especially failure due to thermal loads.

g. The ability to accurately simulate the thermal loads with, if necessary, mechanical loads during structural development and qualification testing.

REQUIREMENT LESSONS LEARNED (A.3.2.12)

See AFFDL-TR-78-8 for historical and other information relating to this requirement.

A.4.2.12 Ultimate loads.

The ultimate loads shall be verified by inspection of strength analyses and tests.

VERIFICATION RATIONALE (A.4.2.12)

Verification of the ultimate loads is needed to assure that the static tests which are performed on the airframe, in fact verify the correct ultimate strength capability required of the airframe.

VERIFICATION GUIDANCE (A.4.2.12)

Ultimate loads reflect the strength needed in the airframe.

VERIFICATION LESSONS LEARNED (A.4.2.12)

A.3.2.12.1 Shipboard landing design loads.

Design loads are those for which compliance with the deformation criteria in 3.2.13 is required.

REQUIREMENT RATIONALE (A.3.2.12.1)

Landing loads for shipboard aircraft resulting from the Navy's multivariate distribution of impact conditions shall meet the deformation criteria of 3.2.13.

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REQUIREMENT GUIDANCE (A.3.2.12.1)

Design loads reflect the strength needed and operability required for shipboard aircraft airframe design.

REQUIREMENT LESSONS LEARNED (A.3.2.12.1)

A.3.2.13 Deformations.

Temperature, load, and other induced structural deformations/deflections resulting from any authorized use and maintenance of the air vehicle shall not:

a. Inhibit or degrade the mechanical operation of the air vehicle or cause bindings or interferences in the control system or between the control surfaces and adjacent structures.

b. Affect the aerodynamic characteristics of the air vehicle to the extent that performance guarantees or flying qualities requirements cannot be met.

c. Result in detrimental deformation, delamination, detrimental buckling, or exceedance of the yield point of any part, component, or assembly which would result in subsequent maintenance actions.

d. Require repair or replacement of any part, component, or assembly.

e. Reduce the clearances between movable parts of the control system and adjacent structures or equipment to values less than the minimum permitted for safe flight.

f. Result in significant changes to the distribution of external or internal loads without due consideration thereof.

REQUIREMENT RATIONALE (A.3.2.13)

Since deformations can influence the performance as well as the structural capability of the air vehicle and airframe, it is necessary to have a requirement identifying those impacts which cannot be tolerated in service.

REQUIREMENT GUIDANCE (A.3.2.13)

Deformations which can modify or degrade the operating capability of the airframe are to be avoided as part of this requirement. Such deformations include those of lifting surfaces which cause a control surface to jam and those which result in maintenance actions of structural repair, fuel leak sealings, etc.

REQUIREMENT LESSONS LEARNED (A.3.2.13)

A.4.2.13 Deformations.

That the air vehicle meets the deformation requirements of 3.2.13 shall be verified by analyses and tests.

VERIFICATION RATIONALE (A.4.2.13)

Verification that the deformation requirements are met is most important from an operational viewpoint, since binding, jamming, buckling, and other deformation induced degradation of operational capability is aggravated by wear and other aging factors which affect structural deformations.

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VERIFICATION GUIDANCE (A.4.2.13)

Deformation requirements can be verified by analyses and tests, however, in very complex structures, emphasis should be placed on verifying these requirements by testing.

VERIFICATION LESSONS LEARNED (A.4.2.13)

A.3.2.14 Service life and usage.

The following parameters are applicable and reflect required operational and maintenance capability for air vehicle structures service life and usage conditions.

REQUIREMENT RATIONALE (A.3.2.14)

This information forms the basis of the design loads/stress spectra and the durability and damage tolerance program. It must represent as accurately as possible both the required functions and the service usage of the system.

REQUIREMENT GUIDANCE (A.3.2.14)

Complete the blanks by entering the service life values provided by basic program directives or by requirements allocation analyses of the basic program directives and historical data from previous systems.

REQUIREMENT LESSONS LEARNED (A.3.2.14)

Premature assessment of service life results in early inspection and modification of a system. When the modification is performed too early, a portion of the useful service life is unused or wasted. After modification, the remaining service life will be adjusted.

Service life specified in the contract may not reflect the actual service life of a system. Manufacture, design tolerances, and usage change may vary the service life significantly. A very large transport was originally projected to have a 30,000 hour service life but ended up with a wing that was good for 8,000 hours. No initial requirement existed to include damage tolerance considerations.

Aircraft designed for high altitude operation required life extension structural modifications when their mission was changed to include high speed, low altitude penetration.

Mission flight plans for strategic aircraft include low level terrain following tracks of specified length. It was found more useful to define the terrain following segment in terms of distance rather than duration, especially in cases where the flight speed was not clearly established. Terrain following tracks should be obtained from the using command. An average track length was found to be approximately 440 NM without reentry. Reentry for a repeat of a race track segment would add on the average 170 NM.

A.3.2.14.1 User identified requirements.

The number of flights, flight hours, shipboard and field operations, landings, mission data, etc. shall be:

a. _________ Service life (Flight hours). In service use, ninety percent of all aircraft shall project to meet or exceed this value for durability and all aircraft shall meet this value with respect to safety.

b. For time dependent design functions, a life of ___________ years.

c. _________ of _________ ground-air-ground cycles (flights).

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d. ________ of _________ field taxi runs.

e. _________ of _________ field takeoffs.

f. _________ of _________ catapult launches.

g. Landings.

(1) _________ of ________ field.

(2) _________ of ________ FCLP (Field Carrier Landing Practice).

(3) _________ of ________ carrier arrested.

(4) _________ of ________ carrier touch-and-go.

h. (_____) mission profiles as specified in ____________.

i. (_____) mission mix as specified in ______________.

j. Other service life and usage as specified in ______.

REQUIREMENT RATIONALE (3.2.14.1)

This requirement is necessary to ensure that quantitative and qualitative performance, operations and support parameters and characteristics are developed in response to and in support of an approved Mission Need Statement (MNS). These user defined requirements (operational requirements) provide a basis for identifying the detail structural design requirements established to ensure system performance objectives are achieved and validated.

REQUIREMENT GUIDANCE (A.3.2.14.1)

The approval of the MNS and the issuance of the Program Management Directive (PMD) mark the beginning of the user defined requirements activity. Such requirements may address operational and support concepts, deployment and employment of the proposed system, missions, mission constraints, operational environments, and effectiveness and system reliability requirements. Those requirements that result in functional requirements for structural performance should be specified in this section. Reference the document which provides the following information or fill in the blank with the planned number of flights, flight hours, landings, mission data, etc. that the typical airframe is expected to experience in one service life.

REQUIREMENT LESSONS LEARNED (A.3.2.14.1)

The requirements specified in this section must reflect applicable mission and operations parameters that promote integrated design approach, considering economics, supportability, producibility, and optimum system commonality.

Minimum requirements must be clearly stated preferably in the context of threshold values. Structural design trades conducted in support of identifying preferred concepts can use threshold values to conduct trades for identification of operationally significant performance above threshold values.

Requirements should establish operational performance criteria and threshold values that are consistent with current capabilities to verify the resulting functional performance through test and/or analysis.

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A.3.2.14.2 Representative basing concept.

Occurrences and durations of taxi, turns, pivoting, braking, fuel and payload loading and unloading, engine trim, runs, towing, and other ground/carrier operations shall be as shown in _______________.

REQUIREMENT RATIONALE (A.3.2.14.2)

See 3.2.14, Requirement Rationale.

REQUIREMENT GUIDANCE (A.3.2.14.2)

Define airport or base layout(s) representative of projected service operations. Include remote or substandard airfields, if appropriate.

REQUIREMENT LESSONS LEARNED (A.3.2.14.2)

A percentage of strategic aircraft in service are rotated on a ground alert mission for a fixed number of days. These ground alerts include recurrent ground movements involving engine starts, taxiing, turns, and runway accelerations to fairly high speeds. A ground alert movement profile should be defined. Determination of the magnitudes of ground turning load occurrences is most readily obtained from historical data. The approach and data of ASD-TR-79-5037 has been applied successfully on a strategic aircraft.

A.3.2.14.3 Repeated loads sources.

All sources of repeated loads shall be considered and included in the development of the service loads spectra and shall not detract from the airframe service life. The following operational and maintenance conditions shall be included as sources of repeated loads:

a. Maneuvers. The maneuver load factor spectra are _______________.

b. Gusts. The gust loads spectra shall be ______________.

c. Suppression Systems - Systems which enhance ride qualities (_____):

(1) Active oscillation control.

(2) Gust alleviation.

(3) Flutter suppression.

(4) Terrain following.

d. Vibration and aeroacoustics. The vibration and aeroacoustic loads spectra and associated duration shall reflect the operational usage of the aircraft as required in 3.5 and 3.6.

e. Landings. The landing loads spectra shall reflect operational parameters and conditions applicable to landings from 3.2 and 3.4.2, respectively. The sink speed spectra are ___________________.

f. Buffet. All static and dynamic sources including the following:

(1) Buffet due to non-linear flow caused by the shedding of vortices during high angle of attack operations.

(2) Buffet due to transonic shock instabilities.

g. Other ground loads. The taxi, braking, brake release, pivoting, turning, towing, and miscellaneous ground loads spectra shall include vertical, lateral, and longitudinal loads and

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accelerations resulting from ground/carrier operations of 3.2.14. These spectra shall include:

(1) Hard and medium braking occurrences per full-stop landings of ______________________.

(2) Pivoting occurrences of _____________________.

(3) Taxiway, ramp, takeoff, and landing roll-out vertical loads spectra resulting from operation on surfaces with roughness of _____________________.

h. Pressurization. (________) The flight number and magnitude of pressurization cycles shall be based on the number of flights, missions, etc. of 3.2.14 plus ground pressure checks. The cockpit and cabin maximum pressures shall be determined using nominal settings of the regulator valves.

i. Repeated operation of movable structures. Impact, operational, and residual loads occurring from the normal operation of movable structures shall be included in applicable loads spectra.

j. Store loads. (____) Carriage and employment loads shall be included in applicable loads spectra.

k. Heat flux. (_____) The repeated heat flux time histories are _______________.

l. Other loads. (_____).

REQUIREMENT RATIONALE (A.3.2.14.3)

All sources of repeated loads affecting the durability and damage tolerance of the airframe must be considered to ensure that the required service life of the system is not degraded. Development of a comprehensive database of load sources, exceedances and other parameters, based on data recorded from actual usage experience, will ensure the greatest possible accuracy in the representation of the design usage and function of the system.

REQUIREMENT GUIDANCE (A.3.2.14.3)

a. Provide load factor spectra representative of projected service operation based on user requirements and the latest ASC Structures Branch and/or NAVAIR historical data. Final maneuver spectra should account for variables such as maneuver capability, tactics, and flight control laws to reflect projected average usage within the design utilization distribution and also usage such that 90 percent of the fleet will be expected to meet the service life. Baseline exceedance data representative of average fleet usage and exceedance adjustments to account for changes in projected service operations are provided to generate exceedance data used in the damage tolerance analysis given in 3.2.14.7. The statistical dispersions provided are used to generate exceedance data used in the durability analysis and test spectra in 3.2.14.6 for which 90 percent of the fleet is expected to experience during the operational service life. Repeated loads sources are documented in ASC-TR-xxxx by aircraft type, mission type, and mission segment. If possible, the maneuver spectra shall be broken down into mission segments and utilize the best historical data available. Careful consideration must be given to defining asymmetric maneuver load factors with their associated conditions and parameters. In some cases, the asymmetric maneuver load factor spectrum can exceed the symmetric load factor spectrum. See the discussion on maneuvers in 3.4.

b. Develop the gust load spectra by continuous turbulence analysis methods provided in ASC-TR-xxxx. See the discussion on gusts in 3.4.

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c. If the aircraft operates with any suppression systems, insert APP. If not, insert N/A. Incremental loads produced by these suppression systems shall be included in all applicable loads spectra. The effect of these incremental loads on the loads spectra shall be determined from the design mission profiles and consider the operational modes of these systems within the mission profiles.

d. Refer to 3.5 and 3.6.

e. Provide cumulative occurrences of sink speed per 1000 landings, by type of landing, typical of projected service operation. ASC-TR-xxxx provides representative data for Air Force and Navy operations. Final data should include the most representative data available. Careful consideration is to be given to STOL operations. If practical, bi-variant tables should be used to present roll versus pitch, etc., probability of occurrence requirements. See ASC-TR-xxxx for taxi vertical load factors at the center of mass of the air vehicle.

f. Develop the buffet loads spectra by analytical predictions of the airframe response generated during flight operations in the buffet regime (e.g. high angle of attack, high dynamic pressure transonic flow). Analytical predictions of buffet loads shall be adjusted, if possible, by wind tunnel data or full-scale flight test data for similar aircraft and configurations. Further information on buffet can be found in 3.4.1.5 and information on transonic flow phenomena can be found in Cunningham, "Practical Problems: Aircraft."

g. Completion of the other ground loads paragraphs will provide the basis for the ground taxi spectra for one service life.

(1) Enter the number of hard and medium braking occurrences per full stop landing along with the associated braking effects. Guidance for braking occurrences is provided in ASC-TR-xxxx. A typical entry would be hard braking with maximum braking effects twice per landing and medium braking with half-maximum braking effects five times per landing. Include anti-skid effects, if applicable.

(2) Enter the number of pivoting occurrences and the corresponding torque load. Guidance for pivoting occurrences is provided in ASC-TR-xxxx. A typical entry would be one per ten landings with self-limit torque load.

(3) Define the roughness characteristics of the airfield(s) from which the airplane is to operate and the number of taxi operations to be conducted on each airfield. Roughness characteristics should be stated as power spectral density roughness levels. Representative roughness levels are presented in ASC-TR-xxxx.

h. If the airplane is to be pressurized, insert APP. If not, insert N/A. The number selected should represent the total number of cycles projected for one service life.

i. The operation of variable geometry flight surfaces, control surfaces, speed brakes, canopies, doors, landing gear, and other devices should be included in service life usage parameters.

j. If the aircraft is required to carry and employ stores, insert APP. If not, insert N/A. Store carriage and employment loads shall be determined for representative store configurations and be included in all applicable loads spectra. Representative store configurations, both like loadings and mixed loadings, should consider both critical design and anticipated future store configurations.

k. If the aircraft is to be operated in flight regimes where aerothermal effects are significant, insert APP. If not, insert N/A. Loads induced by thermal gradients from

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aerothermal effects shall be included in all applicable loads spectra. Time dependent temperature distributions on the airframe shall be determined from the design mission profiles and used to determine the thermal gradients in the structure.

l. List all other repeated load sources which could have an impact on the airframe service life and usage. Appropriate loads spectra should be developed for each of these repeated load sources.

Representative data for various aircraft types are continually accumulated and are documented in ASC-TR-xxxx. Access to and assistance in selection of suitable data will be provided by the Structures Branch (ASC/ENFS), Aeronautical Systems Center, Wright-Patterson Air Force Base OH 45433-7101.

REQUIREMENT LESSONS LEARNED (A.3.2.14.3)

Recorded operational usage data indicates a wide variance in local load factor exceedance spectra for similar aircraft flying the same mission profiles. Factors such as pilot technique, geographical locations, aircraft performance, training, etc., all affect the actual usage any aircraft will experience. To assist in the derivation of an asymmetric maneuver spectrum, a method to estimate the expected roll rate spectrum as a function of the airplane maximum rolling capability and the expected normal load factor spectrum was developed. The results were used in the design and development of a strategic bomber. The development of the roll rate spectrum was published in ASD TR-72-113.

A strategic bomber with an all movable, horizontal stabilizer experienced significant repeated control surface loadings due to surface deflection initiated by the stability and augmentation system in response to lateral gust inputs. These occurrences were not accounted for in the maneuver spectra derived from historical data which is based primarily on intentional maneuvers.

During low level terrain following operations, the aircraft will be subjected to the simultaneous occurrence of maneuver and gusts. For an aircraft required to perform low level terrain following, a maneuver plus gust spectrum was derived from a simulation of flight over specified terrain routes while superimposing random continuous turbulence. The routes were representative of three terrain types describing rugged mountains, weathered mountains, and flat terrains. It was found that the use of more than three routes did not significantly change the character of the maneuver plus gust spectrum.

For a strategic bomber, fly-up maneuvers were assumed to occur twice per low level terrain following segment, once at start of segment and once at the mid-point. Since the fly-up maneuver load factor limits are established outside the normal terrain following load factor limitations, these maneuvers were found to be a very important repeated load source in the durability and damage tolerance design.

Stability augmentation systems and control dynamic effects should be incorporated and developed along with the basic airplane in the dynamic loads gust analyses used to develop gust spectra. Significant changes in spectra have been observed as a result of relatively minor changes in the stability augmentation system description. If such changes are not incorporated in the analyses during design and development of the aircraft, unconservative repeated gust load spectra may be used. The effects of load alleviation or structural mode control systems must be carefully evaluated. These systems may influence the repeated loads differently in various areas, decreasing the gust spectra in one location, while increasing them elsewhere.

The combination of thermal loads and aeroacoustic loadings caused fatigue failures in primary structure very early in the life of a large bomber aircraft. The failures occurred when hot

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surface flow caused skins to distort sufficiently to introduce high mean stresses in skins. The skins then failed in vibratory fatigue.

Many failures have occurred in propeller aircraft fuselage sidewall structure due to the combination of pressure loads and oscillatory pressure fields associated with propeller blade passage.

The service life of transports can be shortened significantly by constant hard landings and using rougher than average airfields.

Edwards and Malone, in a status paper in AGARD-CP-507, point out that for low speed flight where high angles are achieved, fully separated flows are encountered which can range from diffuse vortical flow type make-up to concentrated vortices to enhance stability and control. Interaction of such forebody and wing vortex systems with aft vehicle components results in vortex-induced buffet loads. Figure 6 (from Edwards and Malone in AGARD-CP-507) illustrates typical operating conditions at which such empennage buffet may be encountered. Buffet of horizontal tails can occur at intermediate angles of attack and is a result of the vortex system propagating downstream and encountering the horizontal tail surface. As angle of attack increases, the location of vortex bursting moves upstream in the wake. Loss of lift is associated with the burst location reaching the vicinity of the aircraft, and vertical surfaces located in such regions, such as twin tail configurations, can experience severe dynamic loads and structural fatigue (see example of an air superiority fighter with tip pods on twin vertical tails in Lessons Learned of 3.7.1.1).

For a multirole fighter, actual store configurations employed in the field differed significantly from the baseline configurations used in loads spectra development. The difference in configurations combined with the fact that only inertia loads were used for stores may have had a significant impact on service life, especially for aircraft with heavy air-to-ground usage.

A.3.2.14.4 Other requirements.

Other operational and maintenance requirements affecting the airframe service life or usage are _________.

REQUIREMENT RATIONALE (A.3.2.14.4)

See 3.2.14, Requirement Rationale.

REQUIREMENT GUIDANCE (A.3.2.14.4)

Define requirements or functions which affect airframe service life or usage not otherwise included in 3.2.14. Examples are functional check flights, ground maintenance checks, jacking, and towing.

REQUIREMENT LESSONS LEARNED (A.3.2.14.4)

Service load recorders which are not maintained or logistically supported result in a loss of data which affects the actual service life prediction based on actual usage.

A.3.2.14.5 Airframe structure inspection.

By design, the airframe structure shall not require inspection during the service life specified in 3.2.14.

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REQUIREMENT RATIONALE (A.3.2.14.5)

In order to assure optimal operational cost and safety, the airframe must have adequate durability and damage tolerance capability by design such that when subjected to the expected service loads and environmental spectra there shall not be any inspections required within the service life.

REQUIREMENT GUIDANCE (A.3.2.14.5)

To meet this requirement, the airframe structure should be designed to ensure that cracking or delamination does not occur within two lifetimes of usage and environments specified in 3.2.14.6. In addition, the airframe safety of flight structure should maintain residual strength capabilities within two lifetimes of usage and environments specified in 3.2.14.7.

REQUIREMENT LESSONS LEARNED (A.3.2.14.5)

A.3.2.14.6 Design durability service loads/spectrum.

This spectrum shall represent the service life and usage defined in 3.2.14.1 through 3.2.14.4, adjusted for historical data, potential weight growth, and future aircraft performance at least to initial operation capability (IOC), to reflect severe utilization within the design utilization distribution and such that 90 percent of the fleet will be expected to meet the service life. A flight-by-flight analysis spectrum shall be developed for design durability analysis and a flight-by-flight test spectrum shall be developed for verification tests to verify the structural requirements of 3.11.

REQUIREMENT RATIONALE (3.2.14.6)

The purpose of this requirement is to develop a design durability spectrum to size aircraft structure early in the airplane development. Since the design usage is always different from the majority of the fleet actual usage, the design spectrum should be as close as practical to the most severe usage expected in the fleet to ensure that the majority of the fleet will meet the required service life. A structure designed to the most severe usage of a single aircraft is not considered practical and will compromise the performance of the total aircraft system. Therefore, one way to achieve optimum design is to develop a design durability spectrum which represents at least 90% of the expected fleet usage during the operational service life.

REQUIREMENT GUIDANCE (3.2.14.6)

Historical service life data dictates the need to develop a design durability service loads spectrum which represents more than the average aircraft usage of the fleet. Past programs indicate that an expectation of 90 percent of the fleet meeting the service life requirement is both reasonable and acceptable. The design durability service loads spectrum shall be developed for the design service life and usage requirements of 3.2.14.1 and the representative basing concept of 3.2.14.2. The design durability service loads should represent loads expected to occur in 90% of the fleet operation envelope and should not necessarily be the loads as established for static design criteria. The process of developing a design durability service loads spectrum begins with the selection of all significant repeated loads sources specified in 3.2.14.3 and the selection of chemical, thermal, and climatic environments specified in 3.2.16 and ends once these individual loads spectra are assembled on a flight by flight basis to form the design service loads sequence. For information, repeated loads sources are documented in ASC-TR-xxxx by aircraft type, missions, and mission segments. Baseline exceedance data representative of average fleet usage, statistical dispersions, and exceedance adjustments to account for changes in projected service operations are also provided in this document. The statistical dispersions and exceedance adjustments can be a basis to generate

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exceedance data which 90% of the fleet is expected to experience during the operational service life. Development of a symmetric and asymmetric maneuver loads spectra can be accomplished by use of the repeated loads criteria provided in ASC-TR- xxxx or other rationale. The gust loads spectra is developed by continuous turbulence methods described in the discussion on gusts in 3.4. Ground loads spectra and all significant loads spectra are developed by use of the exceedance data and repeated loads criteria provided in ASC-TR-xxxx plus that developed by the contractor and government for shipboard operations. The flight by flight spectrum is a realistic stress spectrum based on the random ordering of required missions and associated load occurrences, with the exception that shipboard deployment cycles shall be in realistic blocks. Load occurrences less than once per mission segment or once per flight shall be rationally distributed (randomized or ordered, as appropriate) among appropriate segments and flights.

The external discrete flight loads within the spectrum can be developed by various methods. Two representative methods are multiple mission/multiple segment and single weight, and multiple points in the sky. Mission analysis required the appropriate distribution of aircraft weight, center of gravity, altitude, speed, configuration, maneuver usage, and other significant operational parameters within each mission segment. Point in the sky analysis is based on a single reference weight (multiple configurations and center of gravities) along with setting a damage reference level based on single point in the sky for each major airframe component, and then developing a single spectrum of multiple points in the sky such that no single components' damage is less than 80% of its reference level. The reference level is determined for each component based on that component's most critical point in the sky.

Full compliance with this requirement is achieved by development of design analysis and test spectrum as discussed below:

a. Analysis Spectrum. The design durability service loads spectrum may require modifications such as truncation, clipping, and other appropriate techniques in order to achieve a practical/optimal durability analysis. Truncation of the design spectrum is normally required to facilitate the burden of analyzing extremely large numbers of stress cycles which produce negligible damage on aircraft components. High and low stresses in the design spectrum may require clipping of all stress levels above 90% limit load in order to reduce the impact of crack retardation or beneficial residuals for metallic structure. Because composites are very sensitive to high load application and to preclude the development of unconservative analysis spectra, the practice of high load truncation should be avoided. For airframe structures combining metallic and composite structure, the effects of high load truncation should be thoroughly evaluated. The analysis spectrum is generated as a direct result of these spectrum modifications. Particular care should be exercised during the development of this spectrum since it directly influences the damage which each major component will experience during its full service life. In order to assure that each major component is exercised as close as practical to its full service life, a durability analysis spectrum developed by mission analysis methods should have 100% of the equivalent damage of the untruncated spectrum, but some locations could have as little as 95%. A durability analysis spectrum developed by the multiple points in the sky analysis method should result in single component's damage being less than 80% of its reference level.

b. Test Spectrum. Development of the durability test spectrum shall be based on the analysis spectrum. Truncation, elimination, or substitution of stress cycles in the test spectrum may be required to reduce excessive test time and cost for metallic structure. Truncation for composite and hybrid structure (metallic/composite mix) should be evaluated to determine impacts. Durability analysis and development tests will be required to define

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the effect of the differences in time to reach detrimental crack sizes or establish crack initiation by use of the analysis spectrum and proposed test spectrum. The results of these analyses and tests shall be used to establish the final test spectrum and to interpret the test results. Particular care should be exercised during development of the final test spectrum since it is used to demonstrate the airframe service life requirements specified in 3.2.14, identify critical structural areas not previously identified by analyses or development tests, and establish special inspection and modification requirements for the service airframe. In order to assure that the test spectrum satisfies these requirements, a test spectrum goal is to achieve 100% of equivalent damage for the entire airframe but because of practicality, some areas may not achieve this level. Where damage levels will not meet the 100% goal, justification should be provided. To provide assistance in evaluating and investigating fracture surfaces, the test spectrum should include distinguishing indicators such as "Marker Cycles" at specified percentages of the test spectrum. A number between 5% and 10% of full life test spectrum has been used in past programs. The "Marker Cycles" could be a rearranged sequence of flights, regroupment of cycles, or substituted cycles into the test spectrum. The "Marker Cycles" should be verified by element tests to provide readable fracture surfaces with negligible impact on fatigue damage and test time.

REQUIREMENT LESSONS LEARNED (A.3.2.14.6)

Aircraft often experience different uses from those for which they were designed. An example is a multi-role fighter, which is used approximately eight times more severely than its design intended. The current usage of another superiority fighter is approximately four times more severe than its designed plan. The tracking program has revealed that this is mainly attributable to weight increases and operation at Mach numbers higher than originally expected. Early operational service data for an attack aircraft showed that usage was approximately three times more severe than originally intended. This was partly due to an increase in normal load factor spectrum, and partly due to fuel loading in excess of design. The development of a flight by flight spectrum which represents the usage which the majority of the fleet is expected to experience during the operational service life is extremely difficult to achieve. However, this problem can be minimized by careful selection of the most current historical usage data for similar type aircraft and by modifying this usage data to account for changes in projected service operations based on user requirements. A non-readable fracture surface can make it difficult to determine what portion of life was crack initiation and what portion was crack growth. In a full scale fatigue test of a fighter aircraft, a completely random flight sequence of recorded service usage data was employed as the spectrum. The results were mostly non-readable fractures even for tension dominated locations which made the analytical correlation very difficult.

A.3.2.14.7 Design damage tolerance service loads/spectrum.

This spectrum shall represent the service life and usage defined in 3.2.14.1 through 3.2.14.4, adjusted for historical data, potential weight growth, and future aircraft performance at least to initial operation capability (IOC), to reflect baseline utilization within the design utilization distribution and such that the average aircraft usage of the fleet will be expected to meet the service life. A flight-by-flight analysis spectrum shall be developed for design damage tolerance analysis and a flight-by-flight test spectrum shall be developed for verification tests to verify the structural requirements of 3.12.

REQUIREMENT RATIONALE (A.3.2.14.7)

The purpose of this requirement is to develop a design damage tolerance spectrum to size aircraft structure early in the airplane development. A proper balance between performance

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and safety is achieved by designing in the aircraft safety of flight structure to meet the damage tolerance requirements with a spectrum that is representative of the average aircraft usage which the fleet is expected to experience during the operational service life.

REQUIREMENT GUIDANCE (A.3.2.14.7

Based on past experience, the development of the design damage tolerance service loads spectrum should be established from the average aircraft usage of the fleet. The design damage tolerance service loads spectrum shall be developed for the design service life and usage requirements of 3.2.14.1 and the representative basing concept of 3.2.14.2. The design damage tolerance service loads should represent loads expected to occur in the average fleet operation flight envelope and should not necessarily be the loads as established for static design criteria. The process of developing a design damage tolerance service loads spectrum begins with the selection of all significant repeated loads sources specified in 3.2.14.3 and the selection of chemical, thermal, and climatic environments specified in 3.2.16 and ends once these individual loads spectra are assembled on a flight by flight basis to form the design service loads sequence. The repeated loads sources are documented in ASC-TR-xxxx by aircraft type, missions, and mission segments. Baseline exceedance data representative of average fleet usage and exceedance adjustments to account for changes in projected service operations are also provided in this document. Development of a symmetric and asymmetric maneuver loads spectra is accomplished by use of the repeated loads criteria provided in ASC-TR-xxxx. The gust loads spectra is developed by continuous turbulence methods described in the discussion of gusts in 3.4. Ground loads spectra and all significant loads spectra are developed by use of the exceedance data and repeated loads criteria provided in ASC-TR-xxxx. The flight by flight spectrum is a realistic stress spectrum based on the random ordering of required missions and associated load occurrences. Load occurrences less than once per mission segment or once per flight shall be rationally distributed (randomized or ordered, as appropriate) among appropriate segments and flights. An appropriate distribution of aircraft weight, center of gravity, altitude, speed, configuration, and other significant operational parameters shall be made within each mission segment. Full compliance with this requirement is achieved by development of a separate design analysis and test spectrum as discussed below:

a. Analysis Spectrum. The design damage tolerance service loads spectrum may require modifications such as truncation, clipping, and other appropriate techniques in order to achieve a practical damage tolerance analysis. Truncation of the design spectrum is normally required to facilitate the burden of analyzing extremely large numbers of stress cycles which produce negligible damage on aircraft components. High and low stresses in the design spectrum may require clipping of all stress levels above 90% limit load in order to reduce the impact of crack retardation. The analysis spectrum is generated as a direct result of these spectrum modifications. Particular care should be exercised during the development of this spectrum since it directly influences the damage which each major component will experience during its full service life. A developed damage tolerance spectrum should have more than 95% of equivalent damage of the untruncated spectrum.

b. Test Spectrum. Development of the damage tolerance test spectrum shall be based on the analysis spectrum. Truncation, elimination, or substitution of stress cycles in the test spectrum may be required to reduce excessive test time and cost. Damage tolerance analysis and development tests will be required to define the effect of the differences in time to reach detrimental crack sizes by use of the analysis spectrum and proposed test spectrum. The results of these analyses and tests shall be used to establish the final test spectrum and to interpret the test results. Particular care should be exercised during development of the final test spectrum since it is used to demonstrate the airframe service

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life requirements specified in 3.2.14, identify critical structural areas not previously identified by analyses or development tests, and establish special inspection and modification requirements for the service airframe. In order to assure that the test spectrum satisfies these requirements, a damage tolerance test spectrum goal is to achieve 100% of equivalent damage for the entire airframe but because of practicality, some areas may not achieve this level. Where damage levels will not meet the 100% goal, justification should be provided. To provide assistance in evaluating and investigating fracture surfaces, the test spectrum should include distinguishing indicators such as "Marker Cycles" at specified percentages of the test spectrum. A number between 5% and 10% of full life test spectrum has been used in past programs. The "Marker Cycles" could be a rearranged sequence of flights, regroupment of cycles, or substituted cycles into the test spectrum. The "Marker Cycles" should be verified by element tests to provide readable fracture surfaces with negligible impact on fatigue damage and test time.

REQUIREMENT LESSONS LEARNED (A.3.2.14.7)

A.4.2.14 Service life and usage.

The airframe structures service life and usage capability required by 3.2.14 shall be verified by analyses and tests. The requirement of 4.2.14.5 shall be verified by analysis.

VERIFICATION RATIONALE (A.4.2.14)

Each airframe structure responds to its service life and usage in a unique way which must be identified and verified. If not verified, potentially severe service problems can arise, unperceived by the user, which impact the operational readiness of the air vehicle.

VERIFICATION GUIDANCE (A.4.2.14)

The information, data, and parameter values established in response to 3.2.14 requirements are applicable to all of the disciplines and must be validated by all functional areas such as airframe, engine, subsystem, logistics, etc.

VERIFICATION LESSONS LEARNED (A.4.2.14)

A.3.2.15 Atmosphere.

The airframe shall be designed to operate in atmospheres _______________.

REQUIREMENT RATIONALE (A.3.2.15)

The airframe/structure must meet the performance requirements of this specification.

REQUIREMENT GUIDANCE (A.3.2.15)

a. Standard atmosphere. Recommend using table IV of U.S. Standard Atmosphere, dated 1962.

b. Hot atmosphere. MIL-STD-210 contains recorded extremes, operations and five, ten, and twenty percent risk extremes for high temperatures. Surface temperatures are in 5.1.2. High temperature and free air temperatures at altitude are in 5.3.2, High temperature and table XXII. Based upon the use of the air vehicle, select the appropriate reference for hot atmosphere extreme temperatures. Note that the ten and twenty percent risk temperatures of table XXII are close to the hot day temperature extremes of MIL-STD-210.

c. Cold atmosphere. MIL-STD-210 contains recorded extremes, operations and five, ten, and twenty percent risk extremes for low temperatures. Surface temperatures are in 5.1.3

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Low temperature and free air temperatures at altitude are in 5.3.3, Low temperature and table XXIII. Based upon the use of the air vehicle, select the appropriate reference for cold atmosphere extreme temperatures. Note that the ten and twenty percent risk temperatures of table XXIII are close to the cold day temperature extremes of MIL-STD-210.

d. Representative atmosphere. The temperatures in the above atmospheres are world wide extreme temperatures and do not reflect realistic lapse rates. Representative atmospheres useful in mission analyses are tabulated in U.S. Standard Atmosphere Supplements, dated 1966, table 5.2 and discussed in 1.2.1. Reference those atmospheres consistent with the intended location of use and operation of the air vehicle.

REQUIREMENT LESSONS LEARNED (A.3.2.15)

A.4.2.15 Atmosphere.

Analyses and tests shall verify that the airframe can operate in the atmospheres of 3.2.15.

VERIFICATION RATIONALE (A.4.2.15)

Verification that the airframe meets the atmospheric requirements is needed to assure that the operational capability required by the air vehicle is achieved.

VERIFICATION GUIDANCE (A.4.2.15)

Most atmospheric effects can be verified during the course of testing if test planners recognize the need for such testing and plan the appropriate times during the four seasons. Sometimes the upper atmosphere may be colder during the summer months than it is during the winter months.

VERIFICATION LESSONS LEARNED (A.4.2.15)

A.3.2.16 Chemical, thermal, and climatic environments.

The airframe shall be designed to operate in the environments defined below:

a. Ground environments: ________________________.

b. Shipboard environments: Sulfur and nitrogen oxide containing gasses from ship stacks and aircraft exhaust combined with 3.5 percent sodium chloride sea spray to form highly acidic moisture films of pH 2.4 - 4.0. Relative humidity of 70 percent to 100 percent conditions exist simultaneously with sand and dust particle concentrations ranging from 1.32 x 10^{-4} to 4.0 x 10^{-6} lbs/ft^3.

c. Air environments: ____________________________.

d. Man-made environments: ______________________.

e. Usage generated environments: ________________.

f. Maintenance generated environments: _____________________.

REQUIREMENT RATIONALE (A.3.2.16)

These requirements are needed to cover those operational environments to which the airframe will be exposed to assure that adequate structural integrity exists from the viewpoints of corrosion, thermal/mechanical stress interactions, etc.

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REQUIREMENT GUIDANCE (A.3.2.16)

Applicable ground, shipboard, and air environments may be selected from MIL-STD-210, MIL-STD-810, and AFCRL-TR-74-0052. As applicable, heavy rain (8 inches/hour minimum), snow, and icing conditions may be encountered. Consider using FAA requirements for icing condition, FAR, Part 25, Airworthiness Standards, Transport Category Airplanes, Appendix C. In terms of the above references, list the applicable paragraph and table number, title, and any discriminating information, for example, percent risk.

Identify those man-made environments the air vehicle will be reasonably expected to encounter. For example, airborne chemical oxides and residues from power plants, vehicles, etc. may be significant man-made environments. Also, for example, mud, dirt, and other contaminates inside the cargo area resulting from loading, carriage, and unloading of the cargo, including spills of chemicals, may be significant.

The heating incidental to operation of power plants and other heat sources from within the aircraft must be considered. Include steady state and transient excursions of the airframe into and out of regimes of aerodynamic heating consistent with the operational intent. The airframe needs to include provisions for handling the cumulative effects of the temperature/load history for its planned service life. Pre- and post-flight operations such as ground run-up and extended taxiing with the tail to wind need to be considered.

REQUIREMENT LESSONS LEARNED (A.3.2.16)

Specific hot temperature values used for a light air/ground fighter are as listed in table VI.

A.4.2.16 Chemical, thermal, and climatic environments.

Analyses and tests shall verify that the complete airframe can operate in the environment of 3.2.16.

VERIFICATION RATIONALE (A.4.2.16)

Verification that the airframe can withstand the operational environment requirements is needed to assure that the air vehicle has the required operational capability.

VERIFICATION GUIDANCE (A.4.2.16)

Verification that the air vehicle can operate satisfactorily in the required environments is a formidable task if one tries to perform all of the verification tests in real world environments. Most verification testing of this type is done under controlled laboratory conditions and the results extended to the real world operational conditions. MIL-STD-810 can be used as a source of guidance for environmental testing.

Accelerated laboratory tests can be a valuable tool for screening materials for use in a corrosive environment. However, for the results of such tests to have any validity, there must be evidence that a correlation exists with results in the actual environment of interest. The only way to obtain such correlation is by conducting exposure tests in the natural environment. Before attempting to simulate the natural environment, that environment should be characterized as to pH, ions present, temperature, and so forth. A monitor to assess corrosivity, or at least determine times of wetness and dryness, would be useful. When an environment keeps changing as it does on an aircraft carrier, depending on its theater of operation and the time of year, the test should be designed to simulate the most severe condition. It is therefore important to be aware that such variations exist. The cyclic sodium chloride-sulphur dioxide test in accordance with ASTM G85.A4.

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VERIFICATION LESSONS LEARNED (A.4.2.16)

Based on "Developing an Accelerated Test: Problems and Pitfalls," (Laboratory Corrosion Tests and Standards, ASTM STP 866, ASTM, Philadelphia, 1985, pp 14 - 23) the cyclic sodium chloride-sulphur dioxide test in accordance with ASTM G85.A4 gave the best correlation with the carrier environment.

A.3.2.17 Power or thrust loads.

The power or thrust of the installed propulsion system shall be commensurate with the ground and flight conditions of intended use, including system failures of 3.2.22, and the capabilities of the propulsion system and crew. The thrust loads attainable shall include all thrust loads up to the maximum. These loads shall include engine transients due to both normal engine operation as well as the engine system failures of 3.2.22 and __________.

REQUIREMENT RATIONALE (A.3.2.17)

Requiring the thrust or power to be commensurate with the ground and flight conditions of use is needed to preclude extremely arbitrary combinations of propulsive and other parameters arising during design and trying to flight test to, but that can't be achieved in the real world, including likely emergencies from which recovery is expected.

REQUIREMENT GUIDANCE (A.3.2.17)

Propulsive power or thrust greatly affects the sustained maneuvering capability of the air vehicle as well as its performance, particularly speed. The airframe is affected directly and indirectly by the power or thrust used. Engine mount loads are a direct input to the airframe, and the loads induced in the wing during steady state maneuvers are an indirect function of the power or thrust. The flight crew will select the power or thrust settings applicable for the condition, within tolerances and their reaction capabilities, which is of prime concern here and which affects the other factors.

REQUIREMENT LESSONS LEARNED (A.3.2.17)

A.4.2.17 Power or thrust.

Analyses and tests shall verify that the power or thrust used is commensurate with the intended use requirements of 3.2.17.

VERIFICATION RATIONALE (A.4.2.17)

Verification that the power or thrust requirements have been complied with must be accomplished to assure that these effects do not degrade the structural integrity of the airframe or lead to the degradation of the operational capability of the air vehicle from a structure's viewpoint.

VERIFICATION GUIDANCE (A.4.2.17)

Propulsion system power or thrust can influence the structural integrity of the airframe. Analyses and tests need to be performed to verify that the power and thrust requirements of 3.2.17 have been met.

VERIFICATION LESSONS LEARNED (A.4.2.17)

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A.3.2.18 Flight control and stability augmentation devices.

In the generation of loads, flight control and automatic control devices, including load alleviation and ride control devices, shall be in those operative, inoperative, and transient modes for which use is required or likely or due to the system failure conditions of 3.2.22 and __________.

REQUIREMENT RATIONALE (A.3.2.18)

Requiring stability augmentation and similar devices to be in all modes likely to be encountered is needed to assure that adequate structural integrity exists in the airframe to survive expected and likely malfunctions. The requirement also allows advantage to be taken of smaller service induce loads because of properly working stability and load alleviation devices which normally reduce loads and stresses.

REQUIREMENT GUIDANCE (A.3.2.18)

Such controlling devices affect the structural integrity of the airframe, both in short term (strength) and long term (durability and damage tolerance) usage. A failure modes analysis should be examined to assess the likelihood of obtaining adverse control surface deflections and degradation of the stability of the aeroservoelastic system.

REQUIREMENT LESSONS LEARNED (A.3.2.18)

A.4.2.18 Flight control and stability augmentation devices.

Analyses and tests shall verify that the control devices modes of operation are commensurate with the requirements of 3.2.18.

VERIFICATION RATIONALE (A.4.2.18)

Verification that the requirements of 3.2.18 regarding control system effects on the structural integrity of the airframe needs to be done to assure that the operational capability of the air vehicle is adequate to perform its required missions.

VERIFICATION GUIDANCE (A.4.2.18)

Most of the normal modes of operation requirements of 3.2.18 can be verified by both analyses and tests as well as some of the potential failure modes since the control systems are capable of operating in these lesser modes. However, some emergency associated modes of operation would be better verified by ground tests or analyses rather than jeopardize the safety of the crew and air vehicle by performing the test in flight.

VERIFICATION LESSONS LEARNED (A.4.2.18)

A.3.2.19 Materials and processes.

Materials and processes shall be selected in accordance with the following requirements so that the airframe meets the operational and support requirements.

a. Relevant producibility, maintainability, supportablilty, repairability, and availability experience with the same, or similar, materials processes shall be a governing factor for suitability of the airframe design. Environmentally conditioned tests must be performed at the appropriate developmental test level to meet relevant design conditions.

b. Material systems and materials processes selected for design shall be stable, remain fixed, and minimize unique maintenance and repair practices in accordance with the specified operational and support concepts.

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c. Material systems and materials processes (including radioactive materials and processes) shall be environmentally compliant, compliant with best occupational safety and health practices, and minimize hazardous waste generation.

REQUIREMENT RATIONALE (A.3.2.19)

Proper material selection is necessary to assure adequate structural properties, such as strength, stiffness, fatigue, crack growth rates, fracture toughness, corrosion susceptibility, and material system and processes stability for the imposed environment such that operational performance, safety, reliability, and maintainability can be achieved. To avoid shutdown and fines in both manufacture and operation, it is necessary to ensure materials and processes selected are compliant with environmental regulations/laws.

REQUIREMENT GUIDANCE (A.3.2.19)

Guidance from Military Handbooks. Throughout the following sections MIL-HDBK-5, MIL-HDBK-17, and MIL-HDBK-23 are referenced extensively as sources of material allowable data and design application guidance. These documents contain standardized data and procedures for characterizing material systems and analyzing their performance for given applications and product forms and should be used as a baseline for addressing materials and processes characterization, selection and application, and should be deviated from only with appropriate supporting engineering justification.

Guidance from Military Specifications and Design Documents. The guidance contained in MIL-STD-1568, MIL-STD-1587, and SD-24 should serve as baseline data for addressing materials/processes and corrosion requirements and should be deviated from only with appropriate supporting engineering justification. MIL-STD-1568 and MIL-STD-1587 provide extensive guidance/lessons learned for corrosion prevention and control, and materials and processes selection, respectively. MIL-STD-1568 provides guidance for technical planning for corrosion prevention and control, materials and processes selection criteria, and materials and processes performance data and documentation requirements. MIL-STD-1587 and SD-24 provide information relating to materials and processes selection in the design process, material systems performance, and application dependent processes and documentation requirements.

Materials Systems and Materials Processes Selection. The requirements for strength, damage tolerance, durability, flutter, vibrations, sonic fatigue, and weapons effects including battle damage must be defined. One option for establishing material allowables is addressed in ASIP; however, these allowables must be established including environmental effects. Materials and processes should be selected with consideration to minimize unique maintenance or repair practices beyond existing organization, intermediate, or depot (as applicable) capability. The selection of specific material systems should be based on comparison between material properties of all candidate materials and the operational requirements for each particular application. The spectrum of operational requirements that should be considered include: load paths and magnitudes, operating temperatures and environments, including the presence of corrosive and abrasive elements, and water.

Materials should be selected on the basis of suitability and availability, and should include consideration of the additional restrictions created during a national emergency. The use of strategic and critical materials (see definition in MIL-STD-295) should be minimized. Nonstrategic, noncritical materials should be selected when performance, interchangeability, reliability, maintainability, or safety will not be adversely affected, or production significantly altered. Those selected should not include environmentally hazardous materials such as chlorofluorocarbons, asbestos containing materials, paint coatings containing lead, or primer/topcoat paints exceeding volatile organic compound limits.

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The contractor should consider the requirements of the Clean Air Act, Clean Water Act, Toxic Substance Control Act, Resource Conservation and Recovery Act, Superfund Amendments and Reauthorization Act, Emergency Planning and Community Right-To-Know Act, and other service related guidance. The selection of subcontractors should be governed by their ability to comply with the requirements herein.

Manufacturing and in-service damage. Composite structures as well as metal structures must be designed to minimize the economic burden of repairing damage from low energy impacts such as tool drops, etc. To accomplish this goal, the structure is to be divided into two types of regions. The first type is one where there is a relatively high likelihood of damage from maintenance or other sources. The second type of region is one where there is a relatively low probability of the structure being damaged in service. The specific requirements for these two areas are given in tableVII. There are two other threats to the structure that may cause an economic burden or adversely impact safety. These threats are hail damage to the aircraft when parked and runway debris damage to the aircraft from ground operations. The hailstone size for which the structure must be hardened was chosen to include most of the potentially damaging objects found in ground operations. The velocity of these objects is dependent on the weapon system. The details of the hail and runway debris requirements are shown in table VIII. The loading spectrum and environmental conditioning for the testing associated with table VII and table VIII requirements will be the same as that described for the durability tests.

Additional damage considerations. In addition to the threats described above, the safety of flight structure must be designed to meet other damage threats. These threats are those associated with manufacturing and in-service damage from normal usage and battle damage. The non-battle damage sources are described in table IX for manufacturing initial flaws and in-service damage. The design development tests to demonstrate that the structure can tolerate these defects for its design life without in-service inspections should utilize the upper bound spectrum loading and the environmental conditioning developed for the durability tests. These two lifetime tests must show with high confidence that the flawed structure meets the residual strength requirements in table X. These residual strength requirements are the same for the metallic structures.

Special considerations for composites.

For composites, particular emphasis should be placed on the issue of battle damage from weapons since the containment of this damage may well dictate the design configuration. Materials and processes employed in structure must also be selected based on a consideration for repairability for in-service damage. Further, the design usage and missions must be adequately defined such that the potentially damaging high load cases are properly represented.

a. Temperature and moisture. The temperatures should be derived from the projected operational usage of the aircraft and the moisture conditions ranging from dry to the end of lifetime condition expected from a basing scenario that is representative of the worst expected moisture exposure. The allowable for a given flight condition should be based on the temperature appropriate for that flight condition combined with the most critical of the range of possible moisture conditions. The factor of uncertainty to be used in the application of the allowables derived above is 1.5. Since the strength of a composite structure is inherently dependent on the lay up of the laminate, geometry and type of loading, the "B" basis allowable must include these factors. This "B" basis allowable divided by the mean strength of the coupons used for the "B" basis allowable calculation is the fraction of the strength allowed when interpreting the results of single complex component tests.

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b. Low cycle fatigue in composites. Government research programs have demonstrated that aerospace composite structures are relatively insensitive to low cycle fatigue loading for the low stress cycles, but much more damaged by the high stress cycles. Unfortunately, the data base from which the high stress cycles for a new aircraft are derived is somewhat meager. Consequently, care must be used in defining the design usage.

c. Battle damage. For many composite structures, the damage tolerance requirements will determine the allowable strain. However, the battle damage requirements are likely to influence the composite structure arrangement. For example, the need to contain battle damage to prevent catastrophic loss of the aircraft may well dictate the use of fastener systems and/or softening strips. The battle damage threat must be examined in the initial phase of the design. A fall out capability for battle damage based on configurations that meet all other requirements may not be adequate.

d. Extreme loading of composites. Since the composites may be critical for the severe loading cases, care must be exercised to assure that these high level load occurrences are properly taken into account in the force management tracking program.

e. Residual strength. To obtain the desired high confidence that the structure meets the residual strength requirement in the composite components, it may be necessary to show that the growth of the initial flaws is insignificant. Similar to durability testing, there should be a program to assess the sensitivity to changes in the baseline design usage spectrum.

f. Modification programs. For modification programs, reference the requirements of the original development program if they are still technically valid and cost effective. Otherwise leave 3.2.19 unchanged.

REQUIREMENT LESSONS LEARNED (A.3.2.19)

In a fighter airplane, many delaminations occurred between the aluminum skin and aluminum honeycomb in a high temperature and high humidity environment. A recommended improved adhesive system was implemented in the form of a corrosion inhibiting primer, a superior adhesive, and a change to phosphoric acid etching. These improved materials with the requirement for hermetical sealing and for leak checking critical bonded structures plus improvements in the bond shop environment dramatically improved the structure. After the temperature base was established by flight tests, a theoretical damage tolerance assessment program was initiated. This analysis defined such items as type of crack, limit stress, and critical crack length for each component in question.

Cadmium interaction with titanium. Cadmium plate fasteners have been assembled in direct contact with titanium alloy (Ti-6Al-4v) hardware in an all metal weapon system airframe. Cadmium is a widely recognized contaminant of titanium and is generally known to cause embrittlement cracking of titanium. Titanium clips were inspected in two air vehicles to determine if a problem did actually exist. One of the clips, located in a very high temperature area did produce a crack. An extensive investigation to evaluate the effect of Cad/Ti interfaces in actual airframe hardware has been conducted. This survey found:

a. That even though cadmium plated fasteners were being used in conjunction with titanium, no service failures were reported.

b. Additional laboratory tests suggested there might be a problem. The latest literature puts emphasis on laboratory test results involving high tensile stress in the titanium and intimate contact at the Cad/Ti interface at a high temperature. It was apparent that there were conflicts between theoretical results, laboratory results, and actual experience. The literature survey presents a story of laboratory test results with a high percentage of failure

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of cadmium plated titanium fasteners under ideal conditions, to no failures in instances where some of the variables are less than ideal.

After the temperature base was established by flight tests, a theoretical damage tolerance assessment program was initiated. This analysis defined such items as type of crack, limit stress, and critical crack length for each component in question.

Several contractor/military survey teams were assembled to physically examine titanium components in contact with cadmium, especially those exposed to temperatures above 450°F on high time aircraft. A stereoscopic microscope and a fiber optic rod borescope were used in conjunction with fluorescent penetrant to help enhance the capability to locate any cracks around fastener holes. Several components were exchanged and the original part examined by various metallurgical techniques such as the scanning electron microscope and X-ray image scans. No cadmium related cracks were found. Therefore, cadmium/titanium contact on this series aircraft under service environment experienced does not constitute an operational problem.

A realistic laboratory test was devised. Specimens which represented the various Cad/Ti hardware combinations were assembled and exposed for time, temperature, and stress levels of the operational aircraft. The fabrication and assembly were performed by standard manufacturing procedures, except maximum torque values were used, and the installation was made dry (without the use of primer). The results indicated that cracking of titanium components will not occur from solid cadmium embrittlement when exposed to the following conditions:

a. Maximum permissible installation torque.

b. Surface contact between cadmium and base titanium caused by failure to apply epoxy sealant to holes prior to fastener installation.

c. Temperature of 500°F for times equivalent to 8000 hours of service.

d. Overtemperature conditions of 600°F for one hour after completion of exposure of 500°F.

e. Various modes of contact between cadmium and titanium including: thread to thread, shank to hole, and flat surface to flat surface.

Several additional high fit stress (82% of limit) tests were performed at 500°F and 300°F. Cracking occurred in all the titanium holes of the specimens tested at 500°F, but the low temperature specimens did not crack. In actual service all of the significant factors; high stress, high temperature and no diffusion barrier, such as epoxy primer are generally not present and, therefore, cracking does not develop.

Silver plating. Silver embrittlement can pose the same threat as cadmium embrittlement, as was observed in a cowling of a light air/ground fighter.

A helicopter maintenance instruction manual requires conditional use of a petroleum base corrosion preventive compound for engine corrosion control. Current environmental regulations, however, pose new problems associated with the use of petroleum base corrosion preventive compound; emission of the volatile organic compounds, a nonexistent permit to operate the corrosion control cart applying corrosion preventive compound, and no provisions to avoid the removed compound from washing into the storm drains located in or near aircraft parking areas. The long term solution is to apply blade coating to preclude corrosion that eliminates the requirement to use petroleum base corrosion preventive compound.

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The bonding primer used for titanium bonding applications has an 800 grams/liter (gm/l) volatile organic compound (VOC) which exceeds 250 gm/l VOC content environmental regulation (1 Jan 1997). The primer affects the structural integrity of the adhesive bondline. A similar deadline 1 Jan 1993 was dealt with by buying/disposing old cars to offset use of the high VOC content bonding primer. One company addressed this by installing hard controls, but this is an expensive option. Other options include: a) requalify a new primer, b) perform bonding out-of-state, c) seek offsets as in 1993, d) seek exemption, and e) manufacture parts ahead of time.

A.4.2.19 Materials and processes.

Inspections, analyses, and tests shall verify that the materials and processes selected are in compliance with the requirements of 3.2.19. The following requirements also apply:

a. Materials and processes development and characterization and the selection process must be documented. Second source materials (when established as a program requirement) must be qualified and demonstrated through testing to have equivalent performance and fabrication characteristics as the selected baseline material.

b. Materials and processes characteristics for critical parts (see definitions in 6.1.23) shall comply with the requirements of the parts control processes as specified in 3.13.

c. Environmental compliance with all applicable environmental statutes and laws for all materials systems and processes selected must be verified. This shall include life cycle management of hazardous materials.

VERIFICATION RATIONALE (A.4.2.19)

Verification that the materials and processes requirements of 3.2.19 are met is needed to assure that the operational capability of the air vehicle is adequate and sufficient for all required missions and service usage.

VERIFICATION GUIDANCE (A.4.2.19)

Adequacy of materials and processes can best be verified by a combination of analyses, inspection and ground tests. Applicable sections of MIL-STD-1568 and MIL-STD-1587 provide guidance for addressing materials/processes and corrosion verification requirements and should be deviated from only with appropriate supporting engineering justification. Specific additional guidance is provided as follows:

Design development testing. Materials and processes considered for application in the weapon system should be subjected to rigorous evaluation in a well defined and documented design development test program. The principle objectives of such testing are to establish material system performance in the defined operational environments; identify, characterize, and optimize associated stable processes; verify methods used in the evaluation of materials, and establish design. Design properties (in the appropriate chemical, thermal, and climatic environments) must be established during development testing to support transition and application of the material systems and processes into the weapon system.

Building block process. Design development test programs for the characterization of materials and processes typically employ a building block approach consisting of a sequence of coupon, element, and subcomponent tests. Properly implemented, building block tests provide a process for acquiring test data to establish that the material systems and processes will meet the life cycle performance requirements of the weapon system. The following definitions for the building block test specimens are provided:

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Coupons are test specimens of a specific product form and condition subjected to appropriate mechanical and environmental testing in sufficient quantities and in accordance with accepted test methods to establish statistically reliable data on performance. As is often the case, material and product form processes are not fully defined for the material system under evaluation during early coupon testing; ultimately however, final properties established through coupon testing accurately represent manufacturing conditions experienced in a production environment.

Elements are test specimens representative of singular and significant design details of the structural concept under consideration. Elements are subjected to more complex combinations of mechanical loading (as might be experienced in detail parts) in the appropriate environments. Element tests provide additional empirical data on the material system as it may be affected by geometric, product form, and mechanical loading combination affects otherwise not explored in simple coupon testing.

Subcomponent testing encompasses the last significant block of testing (prior to component and full-scale testing) providing useful material system performance data. Material property data is very difficult to extract in testing at the component and full-scale level because of the interaction of complex loads, geometries, and test methods that are not easily or precisely discernible in post-test analysis. Typical subcomponent test articles might include a combination of two or more elements subjected to representative mechanical and environmental loading. Subcomponent test results provide insight into overall structural integrity, inspection requirements and limitations, manufacturing concepts, and maintenance and repair issues.

Anomalies in the performance of the material system and associated processes that appear during the above building block process must be evaluated and addressed by a combination of repeated testing (at the appropriate coupon, element, and/or subcomponent levels) and analysis prior to pursuing the transition of the material system and/or process into the structural design under consideration. Properly implemented, the design development test program will yield the necessary data to establish that material system and associated processes meet generally accepted criteria for transition into a structural design. These criteria include: stabilized material and/or material processes, demonstrated producibility, fully characterized mechanical properties and design allowables, predictability of structural performance and supportability. Refer to a paper entitled "Structural Technology Transition to New Aircraft", Dr. John W. Lincoln, ASC/ENFS, as well as other documents identified in Section 20 of this handbook for additional guidance.

Second source for materials and processes. When industrial base or program requirements dictate a second source for a material system or process, second source equivalency should be established based on demonstrated and documented capability for process compliance and control. Material system and/or process equivalency should also be determined through appropriate mechanical, chemical, environmental, and nondestructive testing/inspection.

Hazardous Materials Management Program Plan. The contractor should plan, develop, implement, monitor, and maintain an effective Hazardous Materials Management Program in accordance with National Aerospace Standard 411. The purpose of this program is to eliminate or reduce (where elimination is not feasible) hazardous and environmentally unacceptable materials. The primary emphasis shall be on eliminating or reducing those hazardous materials and processes that are used or generated during the operation and support of the aircraft. The secondary emphasis shall be on eliminating or reducing those hazardous materials and processes that must ultimately be disposed of when the aircraft has reached the end of its life cycle. The documentation should address how the contractor's Hazardous Materials

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Management Program will reduce the environmental impact of the systems operations, maintenance, repair, demilitarization, and disposal requirements during systems definition, design, engineering development, production, and deployment phases, which are consistent with the design life of the system. Information that should be considered for inclusion in a description of a pollution prevention process includes:

a. Identify methods and procedures for meeting pollution prevention requirements.

b. The methodology for identification of hazardous materials, processes, and waste; including justification for use/substitution and associated cost/benefit analysis.

c. Identify the process for ensuring that all vendors, suppliers, and subcontractors provide all necessary information to meet Hazardous Materials Management Program requirements.

d. Identification of the methodologies for above to be executed including the role of a joint contractor/government Environmental Process Action Team.

Hazardous Materials Management Program Progress. Progress in the prime contractor's hazardous materials management process should be tracked through periodic reporting (reference NAS 411 for guidance). The following information should be provided:

a. Overview of the process, participants, objectives, and accomplishments.

b. Pollution prevention initiatives and status/performance against pre-established criteria.

c. Assessment of new/proposed regulatory initiatives (if applicable).

d. A hazardous materials, processes, and waste list with justification for use.

e. Vendors, suppliers, and subcontractor progress/issues.

f. Identification of regulatory permits required by the government for the operation and support of the aircraft at the government location.

g. Trade-off study results/progress.

Demilitarization and Disposal Plan. The contractor should prepare a Demilitarization and Disposal Plan in accordance with DODINST 5000.2, DOD 4160.21-M-1 (Defense Demilitarization Manual), and NAVAIRINST 4500.11 (Policy and Procedures for Aircraft, Aircraft Engines, and Related Aeronautical Items Reclamation and Disposal Program).

VERIFICATION LESSONS LEARNED (A.4.2.19)

A.3.2.19.1 Materials.

The materials used in the airframe shall be commensurate with the operational and support requirements for the airframe. Whenever materials are proposed for which only a limited amount of data is available, the acquisition activity shall be provided with sufficient background data so that a determination of the suitability of the material can be made. The allowable structural properties shall include all applicable statistical variability and environmental effects, such as exposure to climatic conditions of moisture and temperature; exposure to corrosive and corrosion causing environments; airborne or spilled chemical warfare agents; and maintenance induced environments commensurate with the usage of the airframe. Specific material requirements are:

a. Average values of crack growth data (da/dN) shall be used in the crack growth analysis if the variation of crack growth data is a typical distribution. Reference 3.10.4.4 for a non-typical distribution.

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b. Minimum values of fracture toughness shall be used for residual strength analysis.

c. "A" basis design allowables shall be used in the design of all critical parts (see definitions 6.1.23 through 6.1.23.4). "A" basis design allowables shall also be used in the design of structure not tested to ultimate load in full scale airframe static testing. "B" basis design allowables may be used for all other structure which include: ___________________________.

d. "S" basis design allowables are acceptable for design when "A" or "B" basis allowables are not available, provided they are specified in a governing industry/government document that contains quality assurance provisions at the heat, lot, and batch level in the as-received material condition. Appropriate test coupons shall accompany the material in the as-received condition and shall be subject to testing for verification of minimum design properties after final processing.

e. ______________________________

REQUIREMENT RATIONALE (A.3.2.19.1)

Since different levels of criteria exist for various parts of an airframe, the selection and proportion of metallic and nonmetallic materials must be commensurate with their intended usage. Loading and environmental conditions may influence the selection of a particular material over others. Regardless of material selection, it is appropriate that allowables with the highest probability of meeting minimum values be used in the design of both composite and metallic structural components employed in single load path, non-redundant, and safety of flight critical structure.

It is necessary to select and configure nonmetallic materials that conform to applicable specifications, military standards, and handbooks in order to ensure a more reliable and cost-effective structure.

Nonmetallic materials selection, conforming to approved documentation sources that are called out within drawings and the structural description report, ensure a more reliable strength structure. In order to calculate correct margins of safety, valid material property allowables must be referenced to approved sources within the strength analysis report.

REQUIREMENT GUIDANCE (A.3.2.19.1)

Material Systems Data. MIL-HDBK-5 provides uniform data for metallic materials/components and minimizes the necessity of referring to numerous materials handbooks and bulletins to obtain the allowable stresses and other related properties of materials and structural elements. MIL-HDBK-17 provides data on polymeric composite material systems in a three volume document addressing guidelines for characterization, statistically based mechanical property data, and use of statistical data in design applications. MIL-HDBK-23 provides guidelines and data for design of structural sandwich composites.

The additional guidance on material systems contained in MIL-STD-1568, MIL-STD 1587, and AFSC DH 1-2 should serve as the baseline approach for addressing materials systems requirements and should be deviated from only with appropriate supporting engineering justification. These documents provide extensive guidance/lessons learned for materials and materials processes selection, application, and support throughout the life cycle of the airframe.

Metallic material properties. Properties of materials for design purposes should be obtained from MIL-HDBK-5 or developed, substantiated, and analyzed using statistical analysis criteria and procedures consistent with those presented in MIL-HDBK-5. MIL-HDBK-5 statistical techniques are employed for maintaining uniformity in the presentation of "A" basis allowables,

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whereby 99% of the population of values is expected to equal or exceed the "A" basis mechanical property allowables, with a confidence of 95%. In the presentation of "B" basis allowables, 90% of the population of values is expected to equal or exceed the "B" basis mechanical property allowables with a confidence of 95%. MIL-HDBK-5 represents effect-of-temperature curves on the mechanical properties of metallic properties as well as curves on creep, thermal elongation, and temperature fatigue. Any variance from MIL-HDBK-5 methods for determining reliable mechanical and physical properties should be fully substantiated and documented. Where it is necessary to develop data for materials, the test materials and processes should be those intended for use in production aircraft. The generation and analysis of test data for new material should follow the guideline presented in Chapter 9 of MIL-HDBK-5.

Selection of Steels. Selection of steels should be as follows:

a. Aircraft quality, vacuum-melted steel should be used for parts which are heat treated to an ultimate tensile strength of 200,000 psi and above.

b. The maximum ultimate tensile strength of production parts should not be greater than 20,000 psi above the established allowable minimum requirement.

c. Preference should be given, in selection of carbon and low alloy steels, to compositions having the least hardenability which will provide through-hardening of the part concerned.

d. Compositions should be selected such that heat treatment to the required strength and service temperatures should preclude tempered martensite embrittlement and temper embrittlement.

e. Steels should be selected having ductile-brittle fracture transition temperatures as determined by impact test below the minimum operating temperature.

f. Steels whose mechanical properties are developed by cold deformation should have recovery temperature of at least 50^{o}F above the expected operating temperature range.

g. Critical parts should be designed and processed so as to result in no decarburization in excess of 0.003 in. in highly stressed areas. Elsewhere, decarburization should be avoided, and where unavoidable, should be compensated by appropriate reductions in design fatigue strength. Unless otherwise specified, design should preclude use of as-forged surfaces. Carburization and partial decarburization of fully hardened steel parts should be restricted such that the difference in hardness from the surface to the nominal subsurface hardness should not exceed two (2) Rockwell C (HRC).

h. The mechanical drilling of holes in martensitic steels after hardening to strength levels of 180,000 psi and above should be avoided. When such drilling is unavoidable, the procedure used should be fully substantiated and documented in the appropriate process specification. When required for close tolerance holes or removal of decarburization, holes may be reamed after final heat treatment. Reaming should be followed by retempering at a temperature not more than 50^{o}F below the specified tempering temperature. Reamed holes require a non-embrittling temper etch inspection.

i. Grinding of martensitic steels and chromium plated martensitic steels hardened to 200,000 psi and above should be performed in accordance with MIL-STD-866.

j. Maximum use of materials with high fracture toughness is required. Ferrous materials with fracture toughness of less than 100 ksi-in$^{1/2}$ in the longitudinal direction, and 95 ksi-in$^{1/2}$ in the transverse direction should not be used in fracture critical traceable fracture critical, or maintenance critical applications.

k. H-11, D6-AC, 4340M, and 300M steels should not be used.

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Corrosion-Resistant Steels. The following limitations should be observed in the selection and application of corrosion-resistant steels:

a. Unstabilized austenitic steels should not be fusion welded.

b. Precipitation hardening semi-austenitic grades should not be used in applications which require extended exposure to temperatures in the 750°F through 900°F range.

c. 431 and 19-9DL steel should not be used.

d. Precipitation hardening stainless steels should be aged at temperatures not less than 1025°F. Castings may be aged at 935°F plus or minus 15°F, and springs in the CH900 condition may be used.

e. Corrosion-Resistant Maraging Steels (ALMAR 362, CUSTOM 455, CUSTOM 450) should be aged at temperatures not less than 1000°F.

f. The 400 Series martensitic steels should not be used in the 150,000 to 180,000 psi strength range.

g. Free machining stainless steels should be avoided for all critical applications.

Aluminum Alloys. Whenever the design requires the selection of aluminum for structural applications, maximum use should be made of alloys and heat treatments which minimize susceptibility to pitting, exfoliation, and stress corrosion. Recommended alloys and tempers for exfoliation and stress corrosion resistance are given:

EXFOLIATION RESISTANCE		STRESS CORROSION RESISTANCE	
Alloy	Temper	Alloy	Temper
2014	Artificially Aged	2024	Artificially Aged
2024	Artificially Aged	2124	Artificially Aged
2124	Artificially Aged	2219	Artificially Aged
2219	Artificially Aged	7050	T73XX
7049	T76XX, T73XX	7050	T74XX
7050	T76XX, T74XX	7075	T73XX
7075	T76XX, T74XX	7175	T73XX
7150	T77XX	7175	T74XX
7175	T76XX, T74XX	7475	T73XX

In the event these alloys and tempers, or other approved alloys are not used, the susceptibility to stress corrosion cracking of the selected alloy should be established for each application in accordance with the American Society for Testing and Materials (ASTM), test methods ASTM G44 and ASTM G47.

Clad Aluminum Alloys. Suitably clad or inherently corrosion-resistant alloy should be used in exterior skin which (1) is 0.125 in. or less in thickness, (2) forms a leading edge, exhaust trail area of any source, or wheel well area, (3) is spot or seam welded, or (4) is the face sheet in bonded sandwich construction. To preclude partial aging in heat treatable alloys, the bonded sheet should be in the artificially aged condition prior to bonding. The references above to exterior surfaces and skin mean the external surface only, and do not preclude use of material

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clad only on one side, or the removal of cladding from internal surfaces. Clad, high strength aluminum alloys should not be fusion welded.

Aluminum Alloy Selection Limitations. The use of 2020, 7079, and 7170 is not advisable without engineering justification and procuring activity approval. The use of 2000 series T3 and T4 temper alloys greater than 0.125 in. thickness and 7075-T6 alloys greater than 0.080 in. thickness is not advisable without engineering justification and procuring activity approval.

Titanium and Titanium Alloys. Titanium alloy extrusions should be procured in accordance with the requirements of MIL-T-81556. All titanium bar and forging stock should be procured in accordance with the requirements of MIL-T-9047 or MIL-F-83142 as appropriate and supplemented by such contractor documents as necessary to insure the metallurgical and structural properties required to meet the reliability and durability requirements of the system.

Titanium Sheet and Plate. Titanium sheet and plate stock should be procured to meet the requirements of MIL-T-9046, as supplemented by contractor specifications, drawing notes, or other approved documents which reflect quality, properties, and processing to provide material suitable for its intended use.

Titanium Fretting. Application of titanium should be designed to avoid fretting and the associated reduction in fatigue life. Components should be designed to fretting allowables. Analyses should be conducted for all fretting conditions and should be augmented when necessary by testing to insure that fatigue life requirements are met. In lieu of repeat testing, the results of previous element or component tests that studied fretting may be used to establish design factors for similar applications where fretting may occur.

Titanium Alloy Prohibition. The use of titanium alloy 8Al-1Mo-1V in other than the beta heat treated condition is not recommended without engineering justification and procuring activity approval.

Surface Considerations for Titanium Alloys. All surfaces of titanium parts should be free of alpha case and, if necessary, should be machined or chemically milled to eliminate all contaminated zones or flaws formed during processing. Titanium fasteners or components should not be cadmium or silver plated.

Magnesium Alloys. These alloys are not suitable for salt water environments and should not be used without engineering justification and procuring activity approval.

Beryllium and Beryllium Base Alloys. Beryllium and beryllium based alloys are classified as hazardous material systems and should not be used without the approval of the procuring activity. Beryllium copper alloys containing less than 2% beryllium by weight have generally not been considered hazardous.

Beryllium Copper Alloys. For high bearing load applications, critical wear applications, and wear applications where good structural load capability is required, the use of a beryllium copper alloy is recommended. Alloy UNS C17200 or UNS C17300 or equivalent is required. Wrought beryllium copper should be acquired to ASTM B196, ASTM B197, or ASTM B194. Beryllium copper castings should be acquired to AMS 4890, and classified (class and grade) per MIL-STD-2175.

Bronze Bearing Alloys. For moderate and light duty bearing loads, wrought UNS C63000 aluminum-nickel bronze per ASTM B150 and ASTM B169 is the preferred alloy. Aluminum bronze (alloys UNS C95200-C95800) and manganese bronze (alloys UNS C86100-C86800) castings are acceptable and, where used, should be classified (class and grade per MIL-STD-2175, and acquired per QQ-C-390. The use of bronze alloys other than those discussed above should be avoided.

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Nickel and Cobalt Base (Superalloy) Alloys. The use of nickel and cobalt base superalloys is acceptable. For light gage welded ducting, Inconel 625 (UNS N06625) per AMS 5581, AMS 5599, or equivalent is required. Nickel and cobalt base superalloy casting classification, grade, and inspection standard, with justification including effects of defects analysis, should be fully substantiated and documented.

Material Product Forms.

a. Extrusions. Extrusion should be produced in accordance with QQ-A-200 for aluminum, MIL-S-46059 for steel , and MIL-T-81556 for titanium. Titanium extrusions to be used in applications requiring little or no subsequent machining should be ordered with a class C finish (descaled, free of alpha case).

b. Forgings. All structural forgings should comply with the following requirements. Forgings should be produced in accordance with MIL-F-7190 for steel, MIL-A-22771 for aluminum, and MIL-F-83142 or MIL-T-9047 as appropriate for titanium. The ultrasonic requirements for titanium should be fully substantiated and documented. The forging dimensional design must consider forging allowances such as parting line with regard to final machining such that short transverse grains (end grains) are minimized at the surface of the part. After each forging technique (including degree of reduction) is established, the first production forging should be sectioned and etched to show the grain flow pattern and to determine mechanical properties at critical design points. Sectioning should be repeated after any major change in the forging technique. Orientation of predominant design stresses in a direction parallel to the grain flow should be maximized. The pattern should be essentially free from re-entrant or sharply folded flow lines. All such information should be retained and documented by the contractor.

(1) Residual Stresses in Forgings. Procedures used to fabricate structural forgings for fatigue critical applications should minimize residual tensile stresses. Procedures for heat treatment, straightening and machining should be utilized which ensure minimum residual tensile stresses.

c. Castings including those cold/hot isostatically pressed. (C/HIP). Castings should be classified and inspected in accordance with MIL-STD-2175. Aluminum castings should confirm to the requirements of MIL-A-21180. AMS 5355 should be used for 17-4 pH castings. The use of castings or C/HIPed parts for primary or critical applications requires successful completion of a developmental and qualification program. Avionics equipment castings should be in accordance with MIL-STD-5400.

d. Plate. The use of aluminum alloy plate starting stock equal to or greater than four inches in thickness should be avoided without engineering justification and procuring activity approval.

Composite material properties. Properties for composite materials should be obtained from MIL-HDBK-17 (if available) or developed, substantiated, and analyzed using statistical analysis criteria and procedures consistent with those presented in the appendix to Volume II of MIL-HDBK-17. Additional guidance for design and application of composite material systems are described in MIL-P-9400, MIL-T-29586, and the composites subparagraphs of MIL-STD-1587. These properties should account for those characteristics of fibrous composites which are associated with the required operating environments (including representative moisture conditions), the directionality of the fibers, and the construction variables. The properties should include, but not be limited to, tension, compression, shear fatigue, and the associated elastic constants.

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Selection of composite materials. The selection of the materials to be used for structural applications should take into account all factors which affect required strength, rigidity, and structural reliability. Such factors should include, but are not limited to, chemical characterization of the resin matrix of the composite pre-preg, impact damage, delaminations from manufacturing, scratched, electromagnetic environmental effects, bird strikes, hail damage, manufacturing processes; static, repeated, transient, vibratory, and shock loads; and specific effects of operating environment associated with reduced and elevated temperatures, (including effects of various operating chemicals on composites) repeated exposure to climatic, erosive, and scuffing conditions, the use of protective finishes, the effects of stress concentrations, and the effects of fatigue loads on composite endurance limit and ultimate strength. The actual values of properties used for structural design should include such effects. Field and depot repair procedures should be established for accepted applications of fibrous composite aircraft structures. Such procedures should be documented for subsequent incorporation in pertinent structural repair manuals. Composite material selection should allow a minimum 50°F wet glass transition temperature margin above the service design temperature as measured by dynamic mechanical analysis.

Environmental exposure and conditioning. The temperature exposure range of the composite materials should include the full range of temperatures anticipated during the life of the aircraft including -65°F and aerodynamic heating based on MIL-STD-210 and local heat source effects. The design moisture content should be expressed as a percentage of weight gained due to moisture absorption. The design moisture content should be achieved by subjecting the test specimens to temperatures equal to or less than the maximum operating temperature experienced on the aircraft for a given material system and as percent relative humidity simulating the worst case moisture gain environment until either: (a) a specified percent of weight gain is achieved, (b) equilibrium is reached, or (c) 75 days are needed.

Lamina. For purposes of developing the lamina properties of the fibrous composites, specimens from a minimum of three batches (which includes three resin batches in combination with three fiber lots) of material should be tested to arrive at minimum mechanical properties above which at least 90% of the population values is expected to fall with a confidence of 95%.

Laminates. Composite laminate properties which are established from single ply properties through analytical techniques should be substantiated by the performance of a sufficient number of laminate tests to permit the statistical evaluation of the laminate. This analysis should produce design values for minimum mechanical properties above which at least 90% of the population values are expected to fall with a confidence of 95%. The test data should be correlated with the design values obtained by the analytical techniques and appropriate corrections should be made to the structural design margins-of-safety. When a fibrous composite of specified constituent composition and construction in all respects representative of the material to be used in a new application, has been used previously in sufficient quantities to establish adequacy of its properties, such properties may be used for structural design in the new application. The design allowable for a given environmental condition should be established by testing a reduced number of specimens for combined temperature-moisture environmental conditions. However, the equivalence of the established properties to those for the material intended for the new application should be substantiated by the appropriate tests.

Organic materials. The following restrictions should apply to the selection of elastomers, plastics, and other organic materials used in the fabrication of aircraft structures and components:

a. All organic materials should have resistance to degradation and aging (including resistance to hydrolysis, ozonolysis, and other degradive chemical processes attendant

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upon atmospheric exposure), and minimum flammability consistent with performance requirements for the intended use.

b. Organic materials used in contact with other types of materials, metals, and/or other organics should be separated by suitable barrier materials, should not induce corrosion or stress corrosion, and should be otherwise entirely compatible. Decomposition and other products, including volatile and leachable constituents, released by organic materials under normal operating conditions should not be injurious or otherwise objectionable with respect to materials or components or to personnel with which they may be reasonably expected to come in contact.

c. Cellular plastics, foams, and wood should not be used for skin stabilization in structural components, other than in all-plastic sandwich components as specified herein. Use of foam as sandwich core material should be fully substantiated and documented.

d. Natural leather should not be used.

e. Elastomeric encapsulating compounds used should conform to MIL-S-8516, MIL-S-23586, MIL-M-24041, MIL-A-46146, or MIL-I-81550. Use of hydrolytically unstable encapsulation materials is not advisable without engineering justification and procuring activity approval. Use of polyester polyurethanes requires substantiation of hydrolytic stability.

f. Adhesives used in the fabrication of aircraft structure, including metal faced and metal core sandwich, should be fully substantiated and documented.

g. Integral fuel tank sealing compounds should conform to MIL-S-8784, MIL-S-8802, MIL-S-29574, and MIL-S-83430.

h. Materials that are in direct contact with fuels should be resistant to fuel-related deterioration and capable of preventing leakage of the fuel.

i. All elastomeric components should possess adequate resistance to aging, operational environmental conditions, and fluid exposure for the intended system use.

Transparent materials. Transparent materials used in the fabrication of cockpit canopies, cabin enclosures, windshields, windows, and ports should be limited within the following restrictions:

a. Acrylic plastic should be of the stretched type, conforming to MIL-P-25690. Stretched acrylic plastic should not be used where it will be exposed to temperatures above 250°F.

b. Laminated glass should conform to MIL-G-25871 and bullet resistant glass should conform to MIL-G-5485.

c. The use of polycarbonate should be fully substantiated and documented.

Composite design considerations.

a. Plastics and glass fiber reinforced plastics conventionally conform to the requirements contained in MIL-HDBK-17. Design data and properties may be obtained from MIL-HDBK-17, developed in accordance with the methods prescribed in MIL-HDBK-17, or obtained from other sources subject to the approval by the acquisition activity. The requirements in MIL-STD-1587 covering composites and adhesive bonding are applicable. Base use of glass fiber reinforced plastic upon weight saving, strength maintainability, adequacy of manufacturing methods, and temperature-strength relationship. MIL-P-9400 should be considered in the fabrication of fiber reinforced plastics, using resins which conform to MIL-R-7575, MIL-R-9299, or MIL-R-9300.

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b. Advanced composites materials usually conform to the specifications contained in contractor-prepared documentation acceptable to the acquisition activity. The guidance for composites and adhesive bonding in MIL-STD-1587 should be considered

c. All applicable environmental effects should be accounted for in establishing allowables for structural components. Temperatures should be derived from the projected operational usage of the aircraft and moisture conditions should range from dry to the end of lifetime condition expected from a basing scenario that is representative. The allowable for a given flight condition should be based on the temperature appropriate for that flight condition combined with the most critical of the range of possible moisture conditions. The factor of uncertainty to be used in the application of the allowables derived above is 1.5. Since the strength of a composite structure is inherently dependent on, for example, the lay-up of the laminate, geometry, and type of loading, the allowable must include these factors.

d. Structural sandwich composites design data and properties should satisfy the requirements of applicable sources subject to the approval of the acquisition activity. The guidance on adhesive bonding and sandwich assemblies contained in MIL-STD-1587 as well as those within DN 7B1-11 of AFSC DH 1-2 should be considered. Limit load residual strength of bonded structural components (assuming 100% failure of the bond line) is a baseline performance requirement.

e. Drawings, as well as a structural description report and the strength analyses report, can adequately list approved nonmetallic materials specifications. Allowable military specification or military handbook tabulated property values may be directly referenced in the strength analyses report. Property values from sources other than MIL-HDBK-17, military specifications, or contractor-generated values, previously approved by the acquisition activity, are typically presented in a manner similar to the presentation in MIL-HDBK-5. However, properties which are unique for fibrous composites, due to their special characteristics associated with directionality of fiber and construction variables, are included. A sufficient number of specimens are tested to arrive at "B" minimum mechanical-property values which at least 90% of the population of values is expected to fail with a confidence of 95%. Fibrous construction representative of successful previous usage may be used for structural design in the new application, provided its material properties are established by appropriate test substantiation.

f. Fibrous composite property values, from sources other than MIL-HDBK-17 or contractor generated values previously approved by the acquisition activity, should address the following:

(1) Mechanical properties. Mechanical properties for use as structural design allowables should be furnished for fibrous composites. Such properties should be compatible with the applicable analysis procedures, conditions, and configurations. Typically, the following mechanical properties include:

(a) Tensile ultimate strength-longitudinal (0°) and transverse (90°) including attendant elongation.

(b) Tensile yield strength-longitudinal and transverse.

(c) Compressive ultimate strength-longitudinal and transverse including attendant deformation.

(d) Compressive yield strength-longitudinal and transverse.

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(e) Interlaminar tension

(f) Shear ultimate strength-membrane and interlaminar.

(g) Core shear strength.

(h) Flexural strength.

(i) Bearing ultimate strength.

(j) Bearing yield strength.

(k) Modulus of elasticity.

(l) Poisson's ration.

(m) Density.

(2) Typical properties. Physical properties and certain other properties of the fibrous composite materials intended for use in the design and construction of aircraft should be developed as typical (average) values. For such properties, information on data scatter should be prepared based on applicable test values. Typically such properties include the following:

(a) Full range tensile stress-strain curves with tabulated modulus data.

(b) Full range compressive stress-strain and tangent modulus curves.

(c) Shear stress-strain and tangent modulus curves.

(d) Flexural stress-strain curves.

(e) Fatigue data-tension and tension/compression stress-life curves.

(f) Reduced and elevated temperature effects-temperature range from -65°F to a maximum of +160°F or to the maximum elevated temperature to be encountered by the vehicle under acquisition, whichever is greater.

(g) Directional variation of mechanical properties include 360° polar plots as appropriate.

(h) Pullout strength of material with mechanical fasteners (or without fasteners for cocured/cobonded structure).

(i) Variation of mechanical properties with laminate thickness and with test specimen width.

(j) Creep rupture curves.

(k) Effects of fatigue loads on mechanical properties.

(l) Notch sensitivity.

(m) Climatic effects, including property reduction due to moisture.

(n) Effects of cyclic rate of load on fatigue strength.

(o) Fire resistance.

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(p) Material repairability.

(q) Thermal coefficients.

(3) Special definition of properties. As appropriate, the mechanical and physical properties developed should be specially defined to accommodate unique failure characteristics of fibrous composites. Such definitions include, but are not limited to, yield strength in terms of ultimate stress or secondary modulus; bearing strength associated with hole elongation and shear tear-out criteria; compression strength associated with failure criteria such as crazing or other matrix properties degradation when such degradation is sufficient to result in incipient fatigue failure. Wet properties are established when they differ from dry properties. Material systems which lose strength during the airframe's expected life due to moisture and temperature excursions are to be accounted for in reducing and establishing the "B" allowable strength level.

(4) Substantiation of composite strength. For substantiation of the structural integrity of composites, the following should be established:

(a) Expected absorption rate and saturation level of moisture in the composite matrix.

(b) Resultant strength/modulus and fatigue life degradation associated with this moisture content and expected temperature extremes.

(c) Design allowables reflecting the most extreme applicable conditions.

(d) A statistical description of composite failure parameters achieved by pooling observations from replicated sample sizes of 5 or more to establish batch-to-batch and within-a-batch variability.

(e) Validity of fatigue/environment interaction effects from coupon tests by tests of representative subcomponent structure.

(f) The reduction in residual strength capability as a result of exposure to fatigue loads with thermal and humidity environment (wear-out) for bolted and bonded joints and complex laminate configuration.

(5) Thermal effects. The reduced structural properties due to temperature and other environmental effects must be considered in order to attain structural integrity of the airframe. For example, elevated temperature not only influences the choice of materials but the sizing of structural members as well since thermal stresses are induced by thermal expansion restraint of the fasteners.

REQUIREMENT LESSONS LEARNED (A.3.2.19.1)

With the advent of composite materials, generic properties for a particular resin/fiber material cannot be used as representative within and between disciplines for all structural components. For example, a strength critical wing skin may have different stiffnesses than an aeroelastic critical wing skin made of the same composite material but with different lamina orientations. The material properties used in the final design must be consistent within and between disciplines for the same component from a materials processing and applications viewpoint. Check the material properties development requirements for the different disciplines (strength, aeroelasticity, durability and damage tolerance) for consistency and congruency within the applicable discipline and between all structures disciplines. This requirement is also applicable to other materials, including metallic materials.

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During an evaluation of the effects of various fluids on composite materials, graphite/polyimide coupons in tin cans containing a combination of jet fuel and salt water solution were seen to suffer degradation induced by galvanic corrosion. Testing has shown that the experiment in question was unrealistically severe. However, a unique effect associated with -imide resins in the presence of corrosion by-products was discovered.

The potential for galvanic metal corrosion resulting from contact with graphite reinforced epoxies has long been recognized, and design practices have been established to work around this potential. Sufficient experience is in place such that no design knockdowns are required when working with such materials (MIL-STD-1586: Materials and Processes for Corrosion Prevention and a Control in Aerospace Weapons Systems; MIL-F-7179: Finishes and Coatings, General Specification for Protection of Aircraft and Aircraft Parts).

An industry working group was convened to evaluate the unique -imide phenomenon and develop a recommended position. USAF Wright Laboratory Materials Directorate and Naval Air Warfare Center personnel participated. The results of their findings were presented at a workshop hosted by USAF Wright Laboratory Materials Directorate in 1991.

Findings: The unique findings of this working group was that galvanic corrosion by-products can degrade -imide resins. Testing was performed with various polyimide, fluid, and metal combinations. -Imide resin degradation was found to occur only when: aggressive metal corrosion occurs where there is a mechanism for concentrating hydroxyl ions and where the -OH concentrations are directly in contact with the -imide resin surface. Standard corrosion control procedures were found to be effective in protecting against this phenomenon, and engineering solutions were demonstrated through control of design and material selections.

Service experience with polyimide aircraft structures has shown no such reported corrosion problems.

Refer to MIL-STD-1568, MIL-STD-1587, SD-24, MIL-HDBK-5, AFSC DH 1-2, and AFSC DH 1-7 for additional lessons learned and precautionary information.

A.4.2.19.1 Materials.

The materials used in the airframe and their properties shall be validated by inspections, analyses, and tests to verify that they are in compliance with the requirements of 3.2.19.1. Standardized test methods used to establish metallic and composite material systems properties shall be used, when available. When such standardized methods are not available, a program shall be undertaken to explore and develop standardized test methods. All test methods used in establishing material system performance shall be documented and submitted for procuring activity review.

VERIFICATION RATIONALE (A.4.2.19.1)

The early characterization and selection of materials helps keep the weight and cost of the airframe down while meeting operational and maintenance performance requirements.

VERIFICATION GUIDANCE (A.4.2.19.1)

Materials Systems Testing Data. MIL-HDBK-5 provides uniform data for metallic materials/components and minimizes the necessity of referring to numerous materials handbooks and bulletins to obtain the allowable stresses and other related properties of materials and structural elements. MIL-HDBK-17 provides data on polymeric composite material systems in a three volume document addressing guidelines for characterization and statistically based mechanical property data.

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Materials development and evaluation. Documentation of techniques to be used for process optimization, monitoring, and control should be provided. In addition to process capability, materials should also be quantitatively assessed for risk based on the following criteria: production experience, production capacity, maturity of design allowables, inspectability, availability of sources, and suitability of alternate candidates.

Material substantiating data and analysis. Testing and analysis should be planned and documented to ensure that new or modified materials and processes are characterized in a statistically significant manner relative to the design application, as well as to demonstrate compliance with the requirements herein. The scheduling of characterization testing and analysis should also be documented and specifically related, consistent with a building block approach, to critical path milestones such as first article and test article(s) fabrication, as well as subsequent component qualification test(s).

Material substantiating data and analysis. Documentation of the results of material/process characterization testing and analysis should be provided.

Critical parts first article test. Documentation of the results of first article tests durability and damage tolerant critical parts should be provided. Documentation should include detailed contractor/subcontractor process operation sheets representative of first article manufacture. Differences between processing of the first article and subsequent qualification test article(s) (as fully representative of production) should be specifically identified and substantiated through additional analysis and/or test, and the results provided.

The materials to be used in each of the structural components need to be identified as early in the program as practical. Proper selections of material properties may be verified within the strength analyses, which typically call out the allowables and references.

VERIFICATION LESSONS LEARNED (A.4.2.19.1)

A.3.2.19.2 Processes.

The processes used to prepare and form the materials for use in the airframe as well as joining methods shall be commensurate with the material application. Further, the processes and joining methods shall not contribute to unacceptable degradation of the properties of the materials when the airframe is exposed to operational usage and support environments. Specific material processing requirements are:

a. ____________________.

b. ____________________.

REQUIREMENT RATIONALE (A.3.2.19.2)

This requirement is needed to define material processes and joining methods to ensure adequacy of the airframe in meeting structural integrity requirements.

REQUIREMENT GUIDANCE (A.3.2.19.2)

The guidance contained in MIL-STD-1568 and MIL-STD-1587 should serve as the baseline approach for addressing materials/processes and corrosion requirements and should be deviated from only with appropriate supporting engineering justification. MIL-STD-1568 and MIL-STD-1587 provide extensive guidance/lessons learned for materials processes selection and application.

Metallics processing.

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Heat treatment. Heat treatment of aluminum alloys should be in accordance with the material specification and MIL-H-6088. Titanium should be heat treated in accordance with the material specification and MIL-H-81200. Steels should be heat treated in accordance with the material specification and MIL-H-6875. All reasonable precautions should be taken to minimize distortion during heat treatment. Steel parts which require straightening after hardening to 180,000 psi or below may be cold straightened provided a stress relieving heat treatment is subsequently applied. Except for the 14Co-10Ni family of alloys, straightening of parts hardened to tensile strengths above 180,000 psi ultimate tensile strength should be accomplished at temperatures within the range from the tempering temperature to 50°F below the tempering temperature. The 14Co-10Ni family of alloys may be straightened at room temperature in the as quenched condition (after austenitizing and prior to aging). Parts should be nondestructively inspected for cracks after straightening.

Quench rate sensitivity. Parts produced of materials which (a) require quenching from elevated temperature to obtain required strength and, (b) have corrosion or stress corrosion resistance sensitivity as a function of quench rate should be heat treated in a form as near final size as practicable. Wrought aluminum alloys that meet strength and other requirements and have been mechanically stress relieved by stretching or compressing (TXX51 or TXX52 heat treatments) may be machined directly to the final configuration.

Welding. Welded joints may be utilized in designs where shear stresses are predominant and tensile stresses are a minimum. Weldments involving steels which transform on air cooling to microstructure other than martensite should be normalized or otherwise processed to equivalent hardness in the weld zone. Weldments in parts subject to fatigue conditions should be fully heat treated after welding, unless otherwise specified. Precautionary measures including preheat, interpass temperature control, and postheating should be applied when welding air hardenable steels. Primary structural weldments should be stress relieved after all welding is completed. During welding operations heated metal should be protected from detrimental contaminants. Spot welding of skins and heat shields should be avoided unless approved corrosion control procedures subsequently are applied.

Weld bead removal. To avoid the possibility of stress corrosion or fatigue damage, all weld bead reinforcement of fatigue and fracture critical parts should be accessible for machining after fabrication, and should be fully machined. The weld bead reinforcement on the interior diameter of tubular structures should be fully machined if accessible. Conformance with welding specifications MIL-W-6858 (Resistance Welding), MIL-W-6873 (Flash Welding), and MIL-STD-2219 (Fusion Welding for Aerospace Applications) is required as applicable. Qualification of welding operators should be in accordance with MIL-STD-1595. Weld quality should conform to ASTM E-390, as applicable.

Brazing. Brazing should be in accordance with MIL-B-7883. Subsequent fusion welding operations or other operations which involve high temperature in the area of brazed joints should not be depended upon for any calculated strength in tension. When used, brazed joints should be designed for shear loadings. Allowable shear strengths should conform to those in MIL-HDBK-5. Titanium should not be brazed.

Soldering. Soldering materials and processes should be as specified in MIL-STD-2000. Soldering should not be used as a sole means for securing any part of the airframe or controls. MIL-T-83399 should be complied with for testing for removal of residual flux or by-products after soldering. The contractor should establish a soldering schedule for each joint to be soldered and a flux neutralizing and removal schedule.

Surface finish. The following surface roughness requirements for parts installed in aircraft should apply:

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a. The surface roughness of chemically or electro-chemically milled parts should not be in excess of 200 microinches as defined in ANSI B46.1-1978.

b. The surface roughness of forgings, castings, and machined surfaces not otherwise designated should not be in excess of 250 microinches.

Castings are classified to establish the inspection and test procedures and requirements consistent with the importance and criticality of the part, design stress level of the part, its margin of safety, and the required level of integrity of the part.

Reference the applicable military specifications and documents and provide the indicated requirements in the appropriate blanks. If a subparagraph is not applicable, leave it out and re-letter the following subparagraphs. For castings, MIL-STD-2175 is applicable for classifying and inspecting. For aluminum castings, MIL-A-21180 must be complied with, in structural applications. For magnesium castings, MIL-M-46062 or other casting specifications in MIL-HDBK-5 may be applicable. For steel and CRES castings, AMS 5343 or other casting specifications in MIL-HDBK-5 may be applicable to structural applications. The margins of safety, considering "S" property values, are conventionally not less than 0.33 unless a lower value can be substantiated empirically. For premium grade aluminum castings of the A357-T6 alloy, the following margins of safety on yield and ultimate strength are applicable for the radiographic inspection quality grades as defined in MIL-A-21180. For grades "A" and "B", the margin of safety shall not be less than 0.0. For grades "C" and "D" the margins of safety shall not be less than 0.33 and 1.0, respectively. Flaws shall be assumed to exist in the repaired area and any heat affected zone in the parent material and of a size and shape determined empirically. However, the flaw sizes shall not be less than those required by 4.11.1.1. Other casting requirements may need to be defined and those in AFSC DH 1-7 are applicable.

Forgings have had to conform to MIL-F-7190 for steel, to MIL-A-22771 and QQ-A-367 for aluminum, and to MIL-F-83142 for titanium. These requirements have been proven necessary to assure structural integrity of the airframe.

Metallic parts, especially forgings, exhibit the greatest strength along the grain direction, which is imparted as the metal is worked between the stages of ingot and finished form.

Reference the applicable military specifications and documents and provide the indicated requirements in the appropriate blanks. If a subparagraph is not applicable, leave it out and re-letter the following subparagraphs. For steel forgings, MIL-F-7190 is applicable. For aluminum forgings, MIL-A-22771 or QQ-A-367 is applicable. For titanium forgings, MIL-F-83142 is applicable. Other forging requirements may need to be defined and those within MIL-STD-1568, MIL-STD-1587, and AFSC DH 1-7 are applicable.

For rolled, extruded, or forged material forms, MIL-HDBK-5 tabulates allowable stresses for the longitudinal (L), long transverse (LT), and short transverse (ST) grain directions. Forgings should be formed from such stock and dimensions that work accomplished on the finished shape results in approximately uniform grain size throughout. Employ forging techniques that produce an internal grain flow pattern, so that the direction of flow in highly stressed areas is essentially parallel to the principal stresses. Ensure that the forging grain flow pattern is essentially free from reentrant and sharply folded flow lines. Ensure that the angle of grain direction at the surface does not exceed 90 degrees.

Composites processing. Composite processing should pay strict attention to process control to ensure the full development of engineering properties. Materials allowables development must accurately represent actual manufacturing conditions including lay-up, cutting, drilling, machining, and curing. Statistical Process Control (SPC) should ensure process optimization and control through in-process monitoring and recording. An SPC Plan for composites should

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be established. The SPC Plan should take into account all process variables which influence the final composite product including receiving inspection, handling, environmental controls, dimensional controls, processing, curing, machining, etc.

Shot peening. Metallic parts that require fatigue life enhancement in areas away from fastener holes or corrosion resistance should be shot peened. For non-critical parts, the requirements of AMS 2430L are considered adequate. For critical parts, including 3.1.3.2, fatigue/fracture critical parts; 3.1.3.3, maintenance critical parts; and 3.1.3.4, mission critical parts; the requirements of AMS 2432A should be used.

REQUIREMENT LESSONS LEARNED (A.3.2.19.2)

It has been mandatory to conform to MIL-STD-2175 for classifying and inspecting castings, in order to reduce the possibility of parts failure. The single failure of a Class 1A casting could not only cause significant danger to operating personnel, but could result in loss of the air vehicle. It has also been mandatory to conform to MIL-A-21180 for aluminum, to MIL-M-46062 for magnesium, and to MIL-S-46052 for low alloy steel in the use of high strength casting applications. These specifications are necessary for prescribing the composition, inspection, mechanical properties, and quality assurance requirements of high strength castings produced by any method. It is necessary to limit the margin of safety to 0.33, in order to account for the lower strength of production castings, which may be as low as 75% of MIL-HDBK-5 tabulated values. It is the policy of some contractors to mandate a margin of safety even greater than 0.33.

Experience has shown that special considerations are required in the design and strength analysis of forgings. In general, small quantities of hand forgings, made by blacksmithing bars or billets with flat dies, are less expensive than die forgings, but hand forgings also have lower allowable stress levels. Because of the time required to manufacture dies for die forged parts, it may be necessary to use substitute parts on the earlier production aircraft. These substitute parts may be machined from bar stock or hand forgings. The strength analyst should be aware of the fact that substitute parts have different material properties than die forgings. The design of die forgings dictates the direction of grain flow and the designer strives to make certain that the inherent forging characteristics are used to the best advantage. Reduced mechanical properties usually exist in the vicinity of the parting plane.

Aluminum die forgings are frequently subject to unhealed porosity in the areas of the parting plane. Steel parts are also subject to reduced tensile allowable stresses across the parting plane. Since these characteristics significantly affect the mechanical properties of the finished part, they should be considered in the design, the sizing, and the strength analysis of the forged part.

Experience has shown that most fatigue cracking problems originate on the outer surface of parts. Shot peening has been found to produce compressive stresses in this region and delay the occurrence of this type of cracking. The compressive stresses on the outer surface also have reduced the maintenace burden from corrosion and wear. Parts that are designed with the intent to employ the fatigue benefits of shot peening in meeting the required structural life must use the computer controlled processes of AMS 2432A.

A.4.2.19.2 Processes.

The processes and joining methods applied to the materials used in the airframe shall be validated by inspections, analyses, and tests to verify that they are in compliance with the requirements of 3.2.19.2.

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VERIFICATION RATIONALE (A.4.2.19.2)

The verification of structural material processes and joining methods is needed to ensure that structural integrity is attained and maintained in the airframe components.

VERIFICATION GUIDANCE (A.4.2.19.2)

The verification of the adequacy of structural processes can be accomplished by checking applicable specifications, conducting appropriate inspections, reviewing applicable analyses, and checking the results of tests.

Casting drawings, as well as the structural description report and the strength analysis reports, shall adequately call out the casting specifications. It is conventional to inspect all castings in accordance with MIL-STD-2175. It is also conventional to strength test to destruction the least acceptable castings. These tests also typically verify that the calculated margins of safety, using "S" property values of MIL-HDBK-5, are not less than specified in 3.2.19.2.e.

Forging drawings, as well as a structural description report and the strength analysis reports, can adequately call out the forging specifications. The quality inspection and test guidelines contained within MIL-STD-1587 and AFSC DH 1-7 should be adhered to.

The verification of desired grain directions can be achieved by inspection of drawing notes and parts for compliance with the requirements of 3.2.19.2. Drawings, where applicable, shall indicate and note grain directions. After the forging technique (including degree of working) is established, section and etch the first production forgings to show the grain flow structure.

Composite process verification. Composite manufacturing development and production requires sufficient process verification testing to ensure that engineering design values are maintained. Primary, significant secondary, or process critical composite laminates should undergo destructive test and evaluation to validate critical characteristics such as degree of cure, presence of microcracks, fiber waviness, interlaminar shear strength, porosity, etc. Primary or significant secondary structure should have selected composite process verification elements representative of the critical aircraft structure fabricated from the same material, cured under the same cure cycle parameters, and when possible, on the same tool and as part of the part they represent. Where the size and configuration of the process verification element permits, a structural test coupon simulating the critical failure mode of the structure should be conducted. Otherwise, mechanical verification tests best suited to verify the process should be conducted. Additionally, primary or significant secondary composite part should have at least one representative glass transition (Tg) temperature measurement to verify the degree of cure in the worst case location. Process verification test results should be confirmed with predicted results or results generated from destructive test and evaluation of critical composite structure. The composite structures process verification tests should be provided. A composite process verification plan should be provided.

First part process verification. All primary, significant secondary or process critical composite laminates should undergo destructive test and evaluation. Tests should include nondestructive inspection, dimensional measurements, photomicrographic test analysis of process sensitive areas, glass transition temperature measurement of potential areas of under and over cure, and mechanical tests of local specimens to ensure that resin and fiber/resin dominant design properties are developed during cure. These tests should validate the composite laminating and curing process, as well as, ensure that producibility and process verification is accounted for in design. Composite first part process verification should incorporate the following criteria:

a. Selection of destructive test articles: One each of the primary composite parts should be destructively tested. Each part should be of the same configuration as EMD/production

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parts and be produced using the same tooling and procedures. If significant design modifications, tooling changes or changes in fabrication processes/procedures are made, additional articles should be destructively tested to verify the change for each part affected. The following exceptions apply:

(1) If it can be demonstrated that the left and right hand parts are mirror images (identical details, layups, tooling, and fabrication procedures), then either a left or right hand article will satisfy the requirements for both parts.

(2) Discrepant parts may be used if part discrepancies are considered to be sufficiently minor as to not interfere with the evaluation. Parts with large areas of delaminations, porosity or other defects indicating a major process anomaly should not be used.

b. Scheduling of destructive tests: Although it is preferred that destructive testing be conducted on the first part fabricated, any one of the first five parts may be selected for destructive testing with the following restrictions:

(1) No more than five of each type of part may be produced prior to completion of destructive testing and evaluation.

(2) No assembly of composite primary structural elements may be performed prior to the completion of the destructive test and evaluation of those parts, unless the structure can be easily disassembled.

The plan should describe those efforts to verify manufacturing and assembly processes as well as tooling concepts.

Statistical Process Control (SPC) for Composites. Composite processing should pay strict attention to process control to ensure the full development of engineering properties. Materials allowables development must accurately model actual manufacturing conditions including layup, cutting, drilling, machining, and curing. SPC should ensure process optimization and control through in-process monitoring and recording. SPC should take into account all process variables which influence the final composite product including receiving inspection, handling, environmental controls, dimensional controls, processing, machining, etc. The plan to establish SPC for composites should be developed and provided.

Fluid Resistance/Durability of Composites. A detailed fluid resistance/durability test program should be conducted and documented to include a description of fluid resistance and weathering characteristics for exposure conditions and measurement of mechanical and physical properties and diffusion characteristics.

Shot peening. Parts that are designed with the intent to employ the fatigue benefits of shot peening must validate the reliability of this process through AMS 2432A. In addition to the development of internal procedures, this specification required continuous, built-in classification systems on shot peening machinery to remove broken particles in the process, specific Almen intensity verification locations to be shown on the drawing, computer monitoring of shot flow, movement of part and movement of peening shot stream. Each of these parameters must be continuously monitored by computer with automatic shutdown should any of the prescribed fall out of tolerance.

VERIFICATION LESSONS LEARNED (A.4.2.19.2)

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A.3.2.20 Finishes.

The airframe and its components shall be finished in compliance with the following requirements.

a. Environmental Protection. ________________. Specific organic and inorganic surface treatments and coatings used for corrosion prevention and control must be identified and established.

b. Visibility. ____________________.

c. Identification. _______________.

d. Aerodynamically smooth exterior surfaces. _________________.

e. Other. _______________________.

REQUIREMENT RATIONALE (A.3.2.20)

Structural and other parts of the airframe need to be protected from adverse environments, including man-made as well as natural to enhance their useful life and to reduce maintenance down-time and costs. Visibility and identification finishes used on the airframe must also be addressed to assure that they do not adversely affect the airframe. Environmental regulations/laws must be addressed to ensure the finishes used on the airframe are in compliance with applicable local, state, and federal environmental protection regulations.

REQUIREMENT GUIDANCE (A.3.2.20)

Identify and reference appropriate finish requirements for preservation (including corrosion prevention and control), visibility, and identification, and insert N/A for those areas which are not applicable. The guidance contained in MIL-STD-1568, MIL-S-5002, and MIL-F-7179 should serve as the baseline approach for identification and application finishes and should be deviated from only with appropriate supporting engineering justification. For modification programs reference the requirements of the original development program if they are still technically valid and cost effective. Otherwise, identify and reference applicable portions of MIL-STD-1568, MIL-S-5002, MIL-F-7179, and MIL-M-25047. The selection and application of all organic and inorganic surface treatments and coatings should comply with air quality requirements. Exterior surfaces should be aerodynamically smooth. Organic coatings (other than fire insulating paints) should not be used for temperature control in inaccessible areas.

REQUIREMENT LESSONS LEARNED (A.3.2.20)

Primers, topcoatings, specialty coatings, cleaner, corrosion preventive compounds, etc., have been reformulated to comply with lower volatile organic compounds (VOC) content requirements (environmental regulations).

A.4.2.20 Finishes.

Analyses and tests shall verify that the airframe finishes are in compliance with the requirements of 3.2.20.

VERIFICATION RATIONALE (A.4.2.20)

Verification that the finishes meet the requirements of 3.2.20 needs to be accomplished to assure that the operational capability of the air vehicle is adequate and not degraded because of finish breakdowns and failures.

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VERIFICATION GUIDANCE (A.4.2.20)

Finishes can be verified as meeting the requirements of 3.2.20 by laboratory, ground, and flight testing. Compatibility of the finishes with the material underneath may be accomplished by empirical analysis and inspections derived from previous experience with the finish and material underneath. A finish specification should be prepared using MIL-F-7179 and MIL-S-5002 as a source of guidance.

VERIFICATION LESSONS LEARNED (A.4.2.20)

A.3.2.21 Non-structural coatings, films, and layers.

Coatings (organic and inorganic), films and layers applied or attached to the interior or exterior of the airframe or to subsystem components shall not degrade the structural integrity of the air vehicle below the minimum required by this specification. The coatings, films, and layers shall be sufficiently durable to withstand all flight, ground, and maintenance environments and usage without requiring maintenance during __________________.

REQUIREMENT RATIONALE (A.3.2.21)

Although coatings, films, and layers may be non-structural, their application and attachment to subsystems of the air vehicle including the structure can impact the structural integrity of the airframe. This requirement is needed to assure that the design, manufacture, inspection, use, and maintenance (including repair) of coatings, films, and layers is a fully integrated effort and will not degrade the structural integrity of the airframe.

REQUIREMENT GUIDANCE (A.3.2.21)

The intent of using a coating, film, or layer is to derive a system benefit economically and without penalizing the overall performance of the air vehicle. Trade-off studies should be performed to determine if changes in other systems are viable alternatives. Note the distinction between adhesive bonding and other unidentified attachment methods. Adhesive bonding has been the most attractive attachment method for minimum cost, minimum weight, and good durability. But, adhesive bonds, especially to metallic surfaces, are critically dependent on cleanliness of the surface before bonding. A subtle contamination can reduce the bonded strength to almost zero. There is no known method that will reliably detect this condition. One method of positive bond control is overall proof load testing. Another is local loading by a suction cup or a secondary bonded pad. Contamination typically affects an entire bonded surface rather than a local area, and as such testing of a tag end from each bonded panel may be sufficient. The flight environment will include temperatures, air loads, structural strains and deflections, vibrations, bird impacts, rain, hail, salt air, etc. The ground environment will include humidity, temperature, impact from runway debris, salt spray, fuel and other system fluids, rain, hail, dust, etc. The maintenance environment will include impact damage from dropped tools and line replaceable units, abrasion, and cleaning fluids. In general, both the number of hours of exposure and the number of cycles of application of each parameter may influence the durability behavior of the coating, film or layer, and the means of attachment. The time period inserted in the blank depends upon the requirements of each system, but two airframe service lifetimes of 3.2.14 is recommended. The guidance contained in MIL-STD-1568, MIL-S-5002, and MIL-F-7179 should serve as the baseline approach for identification and application finishes and should be deviated from only with appropriate supporting engineering justification.

REQUIREMENT LESSONS LEARNED (A.3.2.21)

Regarding the need for field repairs, experience has shown that damage does occur and repairs (mostly minor) are needed and are cost effective.

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A.4.2.21 Non-structural coatings, films, and layers.

Analyses and tests shall verify that the airframe non-structural coatings are in compliance with the requirements of 3.2.21. Inspection and repair methods for the coatings, films, and layers shall be provided. Further, methods of nondestructive inspection shall be provided for inspecting the structure behind or beneath the coatings, films, and layers for cracks, failures, damage, corrosion, and other structural integrity anomalies. In particular, if the inspections of 4.11.1.2.2.d and 4.12.1 are applicable to the structure behind or beneath the coatings, films, and layers, the coatings, films, and layers shall not preclude or impede the performance of the durability and damage tolerance inspections. If the coatings, films, or layers are attached by adhesive bonding, a positive bond control system shall be used to minimize the probability of occurrence of a very-low-strength bond and adequate in-process controls during fabrication and final non-destructive inspection techniques shall be established to minimize the probability of bond failure.

VERIFICATION RATIONALE (A.4.2.21)

Verification that the non-structural coatings and films meet the requirements of 3.2.21 is needed to assure that the required operational capability of the air vehicle is not degraded during its service life.

VERIFICATION GUIDANCE (A.4.2.21)

The demonstration that the coating does not degrade structural integrity should show that the coating will not cause stress corrosion cracking or accelerated corrosion of structural members.

If no degradation of engine performance is acceptable, the demonstration should address the probability that fragments of the coating may enter the engine and the performance of the engine with such ingested fragments. The demonstration of durability of the coating should begin with chemical stability of the coating material (and its attaching adhesive if applicable) and compatibility with liquid chemicals associated with USAF aircraft.

Resistance to degradation over the temperature and humidity ranges expected on the aircraft should be addressed next.

Ability to withstand the mechanical environment is the final demonstration, including impact, abrasion, vibration, air loads, and structural deformations. Materials and processes for repairing should demonstrate the same capabilities.

The demonstration of integrity of adhesive bonds will usually consist of process control records and nondestructive inspection for delaminations. In exceptional cases where separation of the coating must be absolutely precluded for every installed coating, the verification should include a proof load test of some kind. Low test loads can be developed by vacuum cups or pressure sensitive adhesive tape. More elaborate procedures would be needed to prove high bond strength of an installed coating.

VERIFICATION LESSONS LEARNED (A.4.2.21)

A.3.2.22 System failures.

All loads resulting from or following the single or multiple system failures defined below whose frequency of occurrence is greater than or equal to the rate specified in 3.2.11 shall be limit loads. Subsequent to a detectable failure, the air vehicle shall be operated with the flight limits of 3.2.5, 3.2.7.10, and 3.2.9.5. Loads resulting from a single component failure shall be designed for as limit load, regardless of probability of occurrence.

a. Tire failures. (_____).

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b. Propulsion system failures. (_____).

c. Radome failures. (_____).

d. Mechanical failures. (_____).

e. Hydraulic failures. (_____).

f. Flight control system failures. (_____).

g. Transparency failures. (_____).

h. Hung stores. (_____).

i. Other failures. (_____). ________________________.

REQUIREMENT RATIONALE (A.3.2.22)

The ability of the airframe to successfully withstand the system failures of 3.2.22 is needed to ensure that the safety of the crew and recovery of the air vehicle is ensured.

Consideration of transparency failures during development of the airframe is needed to establish alternate load paths, to assure adequate strength in structural components impinged upon by any air blast coming through a failed transparency, and to minimize the effects of such failures on the crew and, if applicable, passengers on board the air vehicle.

REQUIREMENT GUIDANCE (A.3.2.22)

This requirement relates to those failures which can be expected during normal operations and includes such things as engine failures, tire failure, hydraulic system failures, autopilot malfunctions, and other failures which have a high likelihood of occurring during the lifetime of any air vehicle. One would not expect to lose the air vehicle because of the occurrence of a likely failure of a component of the air vehicle. All such potential and likely failures are to be identified in this requirement (see 3.4.1.13 and 3.4.2.11).

The consideration that needs to be taken into account is the designing limit loads that occur during or subsequent to the occurrence of a system failure. Such loads may be considered to be random loads. The cutoff frequency of occurrence that would be used to determine whether or not the loads resulting from a possible failure would be included in the limit loads is the same as the cutoff frequency selected for the loads of 3.2.11. Historical data for similar aircraft performing similar missions can be used to determine the rates at which possible failures occur which result in detrimental deformation.

Historical data indicates that any tire should be expected to fail during any phase of taxi, takeoff, flight, or landing and this should be taken into account in the design of the airframe and landing gear. If the probability of the frequency of multiple tire failures occurring during the same flight is greater than or equal to the rate specified in 3.2.11, the worst case combination of multiple tire failures should be taken into account in the design of the airframe and landing gear. In determining failure rates, all phases of taxi, takeoff, flight, and landing should be considered. If necessary, one set of failure rates for conventional and prepared surfaces and another set for austere, unprepared surfaces should be used. Define the applicable tire failures in the blank. If tires are not used on the air vehicle, insert N/A (not applicable) in the blank.

Any likely type of propulsion system failure including the airframe parts of the propulsion system that can have an adverse effect on the structural integrity of the airframe, including extinguishable fires, should be considered. Abrupt engine failure conditions, including unstarts, seizures, and the failure of active cooling systems, should be considered at all speeds. Pilot

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action to mitigate the impact of the failure should be started no earlier than two seconds after the detection of the failure. Define the applicable propulsion system failures in the blank.

Historical data indicate that the likely cause of failure is from bird strikes, hail, or pressurization. The back-up and other structure exposed after the failure of the radome should not deform detrimentally or fail. Define the applicable radome failures in the blank.

The expanded use of composites (dielectrics in particular) may have unique structural integrity implications as in the use of radar absorbing structure of various kinds for stealthy aircraft configurations. The emphasis here will probably be on secondary structures (LEs, TEs, fairings, windows, etc.) as well as the internal nacelle duct walls which may be more critical to flight safety. There is also some indication that dielectrics may be useful as radar attenuators in the outer layers of composite skins for wing and empennage surfaces. Conflicting requirements may have a tendency to arise from the matrix of structural integrity, electromagnetic compatibility, lightning protection, and radar attenuation needs. If the structural strength of a component is compromised for stealth or other reasons, the likelihood of a failure increases. Any such failure comes under the above requirement and must be accounted for, particularly the strength of the back-up structure must be adequate to take any loads induced by the failure.

Historical data indicate that mechanical systems such as cargo ramps, cargo doors, latching mechanisms, speed brake support structure, slats, flaps, slat/flap tracks, and drive mechanisms fail more frequently than 1×10^{-7} times per flight. Such failures should not degrade, damage, or cause to fail any other components of the flight control, fuel, hydraulic, secondary power or other flight critical systems such that safe, continued, and controlled flight is not possible.

Hydraulic failures must not be allowed to induce failures in the airframe. Areas of concern include those where a hydraulic failure could cause hard over of a control surface, full brake pressure to be applied to the wheel brakes, or air vehicle configuration changes at airspeeds outside of established envelopes. Define the applicable hydraulic failures in the blank.

The single and multiple failures of the flight control system allowed prior to complete loss of control of the air vehicle should be defined so that the loads acting on the airframe during the failure, as a result of the failure, and following the reconfiguration of the control system to maintain control of the air vehicle can be determined. Define the applicable flight control system failures in the blank.

Flight control systems are becoming quite complex; however, they all function based on some pilot or crew member command resulting in some control surface response inducing an anticipated air vehicle response. Any single element failure of the flight control system which prevents the pilot's command from resulting in a reasonable air vehicle response is a candidate for causing a potential airframe problem.

Consideration of transparency failures during development of the airframe is needed to establish alternate load paths, to assure adequate strength in structural components impinged upon by any air blast coming through a failed transparency, and to minimize the effects of such failures on the crew and, if applicable, passengers on board the air vehicle.

List all other failures that can have an impact upon the structural integrity of the airframe. Special consideration should be given to new or unique systems. Examples of such systems are pneumatic systems and structural active cooling systems.

REQUIREMENT LESSONS LEARNED (A.3.2.22)

Heavy air/ground fighter: Aircraft blew both main tires upon landing. Touchdown was approximately 1100 feet down runway. Upon touchdown, smoke was observed from behind

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both main gears. One thousand feet down runway from touchdown, sparks from both main gears followed by flames. At approximately 3000 feet from touchdown, aircraft veered to left side of runway. Aircraft departed runway 3500 feet from touchdown, with a counter-clockwise spin and came to a stop with right main gear buried in the mud. Left main and nose gear were still on the runway. The WSO exited from the rear cockpit via emergency ground egress. Pilot shut down both engines and exited aircraft normally.

Trainer/transport: Tire blowouts and loss of directional control have contributed to 66 aircraft accidents and incidents since 1971. Incorporation of an anti-skid modification was subject to numerous delays which were caused by quality control and design problems, long lead times for delivery of components, and a strike.

Very large transport: During second takeoff attempt, local runway supervisor notified pilot that he appeared to have blown a tire. Takeoff was aborted and stopping roll became extremely rough. Aircraft was stopped; crew and passengers deplaned on runway. Damaged parts included: six tires, two rims, and minor structural damage in wheel well.

Delta wing fighter: The mission was briefed and flown as a student intercept training mission. During the Weapons Systems Evaluator Missile (WSEM) pass the pneumatic pressure light illuminated, therefore, the planned formation landing was not flown. On or immediately after touchdown, the left main tire blew. The aircraft departed the left side of the runway. Shortly before the aircraft came to a stop in the soft earth, the nose gear collapsed and the aircraft fell on its nose.

Prototype fighter aircraft: Part of the landing gear strut mechanism on this aircraft extended in a downward and forward direction from the wheel axle. With a normally-inflated tire no problems existed; however, with a deflated tire or after loss of a tire, the clearance of the mechanism above the runway was less than three inches and it extended beyond the wheel rim. As a result, the mechanism rode under and snagged the barrier arrestment cable. The resulting loads collapsed the gear rearward. The aircraft went off the runway and sustained major damage.

Heavy air/ground fighter: Engine explosion in flight. While flying a low level route, 17 minutes after takeoff, the crew heard a loud explosion and felt the aircraft vibrate. The left engine fire light came on and the No. 1 engine was shutdown. The left fire light remained illuminated for the rest of the flight. A chase aircraft (from another wing) observed a large hole in the fuselage in the vicinity of the left engine turbine section. The aircrew performed a controlled jettison of external fuel tanks in the jettison area. A single engine landing and normal egress were accomplished.

A very large transport aircraft was lost because hydraulic lines were routed in such a way that failure of the pressure door caused loss of control to an extent that return to base was not possible.

Supersonic trainer: Flaps were full down prior to initiating final turn for a full stop landing. Once rolled out on final, the aircrew heard a pop and noted that it took excessive aileron to keep wings level. The left flap was full up and the right full down. The IP initiated a go-round and retracted the flaps. An uneventful no flap, full stop landing was accomplished. Investigation revealed the left flap operating rod end broke, allowing the flap to retract. Rod end failed at 929 hours and is a 1200 hour time change item.

Supersonic trainer: This split flaps mishap is similar to the one reported where the left flap lower rod end broke and caused the left flap to retract. The student made a no flap landing without further incident. Rod end failed at 646 hours.

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Air supremacy fighter: During an inspection on an aircraft two wing attach bolts which retain the wing to fuselage attach pins in proper position were found to be missing from the wing attach pins. This was the result of improperly installed washers on the bolts which retain the wing attach pins.

Swing wing fighter: The overheat sensing elements in the lower crossover area between the engine bay and the wheel well did not respond until an overheat condition reached 575°F. Approximately five aircraft had hot air leaks that were not detected, but did get hot enough to burst the frangible disc on the fire extinguishing bottle resulting in loss of the extinguishing agent.

Swing wing fighter: During post flight inspection, a section of the left aft spike tip assembly was found lying in the engine intake. The spike aft tip attaching eye bolt had broken and the tip assembly had slipped off and gone into the engine. Engine damage was confined to the first stage fan section. No engine damage resulted from the second reported failure. The exhibit eye bolts failed from an overload condition. It is suspected that the overload was the result of overtorqued latch assemblies. Casting shrinkage cracks were noted at the break area. Six eye bolt samples with existing shrinkage cracks were destruct tested and they exceeded design specification requirements with only one exception. Existing shrinkage cracks were determined to not seriously weaken the eye bolt. ECOs were incorporated into drawings to increase the eye radius and reduce the heat treat hardness to eliminate the shrinkage cracks.

Large transport: Problem noted on functional check flight from Robins AFB when pilot experienced difficulty in holding the wings level. A scan of the wings revealed that the right aileron was up even though the pilot was holding a significant opposite aileron input. Inspection of the aileron system after landing showed that the aileron fairing had contacted the access door cover assembly and jammed in the up position.

Air superiority fighter: High angle of attack maneuvers caused high vibration levels in the stabilator actuators at a resonant frequency causing failure of the input lever. Failure of the input lever resulted in a hard over command and loss of control of the aircraft. The aircraft crashed. The solution involved improving the structural integrity of the actuator and incorporating a centering spring in the control valves to prevent hard over commands to the control surfaces.

Historical data indicate the transparencies fail or are severely damaged more frequently than 1×10^{-7} times per flight. Such failures are often caused by foreign object damage. The modes of failure and the resulting redistribution of loads, both internal and external, need to be determined. Define the applicable transparency failures in the blank.

Transport: From 1965 to July 1981, there were 60 reported Air Force instances of life raft deployments. In addition to the cost of lost equipment and the risk from falling objects, the possibility of losing an aircraft and crew exists. In several instances, aircrews experienced severe control difficulties. The most recent attempt to eliminate inadvertent life raft deployments was the acquisition and installation of a new valve. We have experienced an increase in inadvertent deployments since installing the new valve and have gone back to the old valve and careful evacuation of the life rafts.

A.4.2.22 System failures.

Analyses and tests shall verify that the airframe structure complies with the failure requirements of 3.2.22.

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VERIFICATION RATIONALE (A.4.2.22)

Verification of the adequacy of the airframe to withstand successfully system failures of 3.2.22 is needed to assure that adequate structural integrity exists in the airframe, particularly for expected failures, so that safety of the crew and recovery of the air vehicle is optimized.

VERIFICATION GUIDANCE (A.4.2.22)

Verify as many system failures by analysis and laboratory tests as practical to reduce the risk of damage to the air vehicle and crew. Some system failures may occur during other ground and flight tests and can be used as applicable verification if adequate and sufficient information is also available to document the occurrence and hence the validation.

VERIFICATION LESSONS LEARNED (A.4.2.22)

A.3.2.23 Lightning strikes and electrostatic charge.

The following electricity phenomena occurring separately shall not degrade, damage, or cause to fail critical components of the airframe when airborne such that safe, continued, and controlled flight is in question and, additionally, shall not cause injury to support personnel servicing or maintaining the air vehicle.

A.3.2.23.1. Lightning protection. (____)

The airframe shall be capable of withstanding _______________.

REQUIREMENT RATIONALE (A.3.2.23.1)

Operational use of any air vehicle will require it to fly into atmospheric conditions conducive to its being subjected to lightning strikes. Strikes occur often at substantial distances from obvious thunder storm cells. This requirement is needed to protect the air vehicle structure from significant lightning damage and to preclude loss of an air vehicle.

There are concerns relating to the expanded use of composites which have generally been of secondary importance in predominately metal aircraft. These concerns arise from the lower conductivity of graphite/epoxy materials and the non-conductivity of other materials. The structural response to lightning differs from that of metals. The use of composite structural materials as an electrical ground plane and as a shield for the attenuation of electromagnetic fields requires special joining techniques, surface treatments, coatings, edge treatments, etc. Sparking hazards are potentially more prevalent in fuel tanks constructed of the less conductive materials. Design practices need to be developed to provide composite material airframes with the electrical properties necessary to assure vehicle safety. Fuel tanks built of composite structures can be designed to be spark free to the direct strike lightning environment.

REQUIREMENT GUIDANCE (A.3.2.23.1)

Complete the blank with the applicable lightning environment that the airframe will be exposed to. Generally, this blank is filled in with "the lightning environments defined in requirements derived from MIL-STD-1795." MIL-STD-1795 is a MIL PRIME standard that defines the external lightning environment that the air vehicle structure needs to be able to withstand. The airframe must withstand lightning strikes without jeopardizing the crew, degrading the structural integrity of the airframe, or requiring unscheduled maintenance time to repair damage or replace parts. MIL-STD-1795 contains a requirement for a lightning protection program to assure that all aspects of providing lightning protection for an air vehicle are considered. MIL-STD-1795 is virtually identical to the lightning requirements imposed by the FAA on commercial aircraft and is in the process of being adopted by NATO countries.

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REQUIREMENT LESSONS LEARNED (A.3.2.23.1)

Tanker/transport: A lightning strike to the aircraft caused an explosion in a reserve fuel tank and loss of twenty-four feet of the outboard wing. Four other wing tip explosions during a three-year period were caused by lightning strikes and ignition of fuel vapors in the wing tip cavity on this same type aircraft. Modification to the wing tip assembly was required to eliminate the potential of an arc occurring during a lightning strike.

Fighter: The airplane was carrying an empty external fuel tank and was struck by lightning which resulted in an explosion of the external tank. This explosion resulted in fragments severing the hydraulic lines and resulted in loss of the aircraft. Design changes to the fuel tank were required to eliminate arcing. This was a case where the aircraft was designed to the lightning requirements but overlooked on the fuel tank.

Bomber: The aircraft, on a training mission, approached a steadily lowering ceiling with associated rain showers and elected to discontinue terrain following and climb to IFR conditions. About 30 seconds after entering the clouds, the crew saw a bright flash and felt a jolt and heard a loud bang. The weather radar was showing no weather returns. One side of the vertical stabilizer lost a 6-foot section and the other side had a 3-foot by 3-foot section.

Swing wing fighter: A flight of three aircraft showed no weather on their radars, however, all three aircraft were struck by lightning. There was a momentary interruption of flight instruments, then all systems returned to normal. Shortly afterward, the flight broke up for separate approaches and one aircraft was hit by lightning again, this time losing all instruments except standby. One engine also experienced an overheat indication.

A.3.2.23.2. Electrostatic charge control. (____)

The airframe shall be capable of adequately controlling and dissipating the buildup of electrostatic charges for ________________.

REQUIREMENT RATIONALE (A.3.2.23.2)

As aircraft fly, they encounter dust, rain, snow, ice, etc, which results in an electrostatic charge buildup on the structure due to the phenomenon called precipitation static charging. Means must be used to safely discharge this buildup so that it does not cause interference to avionics systems or constitute a shock hazard to personnel. During maintenance, contact with the structure can create an electrostatic charge buildup, particularly on non-conductive surfaces. This can constitute a safety hazard to personnel or fuel.

REQUIREMENT GUIDANCE (A.3.2.23.2)

This paragraph is generally applicable to all structural systems. Generally, the blank is completed with "internal and external portions of the air vehicle, in particular those components exposed to air flow or personnel contact." Any component of the structure can accumulate an electrostatic charge and adequate means must be provided to dissipate the charge from the aircraft at a low level so as not to cause electromagnetic interference to avionics, shock hazard to personnel, puncture of materials, etc. Also, retained charge after landing may pose a shock hazard to ground personnel. All components need to be electrically bonded to provide a continuous electrical path to dissipate the electrostatic charge. Non-conductive components of the structure will require special attention. They do not provide an inherent means for the electrostatic charge to dissipate; therefore, some technique will need to be provided to dissipate the charge as it accumulates. MIL-E-6051 provides some additional requirements on precipitation static discharging and the use of conductive coatings for external air vehicle structure. In general, all internal and external sections of the air vehicle structure will require

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some type of conductive coating. For most applications 10E6 to 10E9 ohms per square is required to dissipate the charge buildup. The shock hazard to personnel starts to be felt at about 3000 volts. As a rule, the charge on airframe components should not be allowed to exceed 2500 volts.

REQUIREMENT LESSONS LEARNED (A.3.2.23.2)

This requirement is important to all aircraft structures with special emphasis required for non-conductive structural components. On all aircraft means must be provided to dissipate the normal precipitation static charge buildup accumulated during flight. This is normally done by the installation of precipitation static dischargers on trailing edges. Non-conductive sections must be provided with conductive coatings.

An aircraft had a small section of the external structure made of fiberglass. Post flight inspections required personnel to get in close proximity to this non-conductive structural component. On several occasions, personnel received significant electrical discharges which caused them to fall off ladders and receive injury. Corrective action was easily accomplished by applying a conductive paint to the fiberglass area and providing an electrical bond to the rest of the aircraft structure. Generally, 10^6 to 10^9 ohms per square is adequate to dissipate an electrostatic charge.

In another incident a maintenance person working inside a bomb bay next to non-conductive panels, generated a charge on himself by contact with the panel and created an electrical arc as he was opening a fuel tank access panel.

Fighter: The aircraft was experiencing severe degradation of the UHF receiver when flying in or near clouds. Investigation revealed that the aircraft was not equipped with precipitation static dischargers and the normal precipitation static buildup and subsequent uncontrolled discharge was causing electromagnetic interference to the radio. Installing precipitation static discharges on the aircraft solved the problem.

A.4.2.23 Lightning strikes and electrostatic charge.

Analyses and tests shall verify that the airframe structure complies with the lightning strike requirements of 3.2.23.

A.4.2.23.1 Lightning protection. (___)

Analysis and tests shall verify that the airframe structure complies with the lightning protection requirements of 3.2.23.a.

VERIFICATION RATIONALE (A.4.2.23.1)

Verification is needed of the capability of the airframe and its components to withstand lightning strikes without jeopardizing the air vehicle's performance of its mission or requiring unscheduled maintenance time to repair damage.

VERIFICATION GUIDANCE (A.4.2.23.1)

The analysis and tests must be adequate for the type of structure, metallic, composite, or a combination and reflect state of the art techniques of adequate confidence in the design. Full scale testing may be required to prove certain components (and hence the airframe) meet the requirements of 3.2.23. MIL-STD-1795 contains details on what type of requirement demonstration is considered adequate. MIL-STD-1757 contains lightning test techniques that may be used in verifying the design of the structural components. These requirements replace the previous lightning requirements specified in MIL-B-5087.

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VERIFICATION LESSONS LEARNED (A.4.2.23.1)

Lightning testing may not be required if previous test data is available and applicable. For example, 0.080 inch of painted aluminum structure has been shown by test to be sufficient to prevent puncture by lightning. However, testing may be necessary to show that the component material thickness equals or exceeds the required thickness. Comparable data for composite structures is not available. Most new composite structural materials and joints require testing. Testing is also required if different manufacturing techniques are used such as different types of fasteners on structural joints.

Some amount of testing is usually required. For instance, the fasteners used in joints have a significant impact on the capability of the joints to conduct the lightning currents. Different companies use different fasteners and installation techniques, therefore, previous test data from one contractor may not be directly applicable to the design of another contractor.

A.4.2.23.2 Electrostatic charge control. (___)

Analyses and tests shall verify that the airframe structure complies with the electrostatic charge control requirements of 3.2.23.b.

VERIFICATION RATIONALE (A.4.2.23.2)

Verification is needed to demonstrate that any precipitation static or electrostatic charge buildup on the structural components of the air vehicle is safely dissipated.

VERIFICATION GUIDANCE (A.4.2.23.2)

The analyses and tests must be adequate for the type of structural material being used. In most cases verification that the surface resistivity is within approved design limits will be adequate demonstration that this requirement has been met. In other cases, laboratory and flight tests may be needed.

VERIFICATION LESSONS LEARNED (A.4.2.23.2)

For all structural components this verification must be done during structural component buildup to verify that all components are adequately bonded electrically to each other. After manufacturing is completed, access to some components may not be easily obtained to verify the requirement has been met.

Designers and structural engineers must maintain an awareness of this electrostatic charge control requirement. For example, a structural component was changed from aluminum to fiberglass and experienced electrostatic charge build up in flight, resulting in electrical shock to ground personnel. This material change was made without consideration of the potential for electrostatic charge build up and without an awareness of the impact on the user that resulted in a very expensive modification.

A.3.2.24 Foreign object damage (FOD). (____)

The airframe shall be designed to withstand the FOD environments listed below. These FOD environments shall not result in the loss of the air vehicle or shall not incapacitate the pilot or crew with a frequency equal to or greater than ________________ per flight. These FOD environments shall not cause unacceptable damage to the airframe with a frequency equal to or greater than _______________ per flight.

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A.3.2.24.1 Bird FOD. (____).

The airframe shall be designed to withstand the impact of _______________ pound birds with the corresponding air vehicle speeds of _______________ KTAS in a manner consistent with the normal flight without loss of the air vehicle or the incapacitation of the pilot or crew. The airframe shall be designed to withstand the impact of _______________ pound birds with the corresponding air vehicle speeds of _______________ KTAS with no unacceptable damage. Unacceptable damage is _______________.

A.3.2.24.2 Hail FOD. (____).

The airframe shall be designed to withstand the impact of _______________ hail with the corresponding air vehicle speeds of _______________ KTAS in a manner consistent with normal flight without loss of the air vehicle or the incapacitation of the pilot or crew. The airframe shall be designed to withstand the impact of _______________ hail with the corresponding air vehicle speeds of _______________ KTAS with no unacceptable damage. Unacceptable damage is _______________.

A.3.2.24.3 Runway, taxiway, and ramp debris FOD. (____).

The airframe shall be designed to withstand the impact of _______________ FOD during any phase of taxi, takeoff, and landing without loss of the air vehicle or the incapacitation of the pilot or crew. The airframe shall be designed to withstand the impact of _______________ FOD during any phase of taxi, takeoff, and landing with no unacceptable damage. Unacceptable damage is _____________.

A.3.2.24.4 Other FOD. (____).

__________________________.

REQUIREMENT RATIONALE (A.3.2.24 through 3.2.24.4)

Foreign object impingement is difficult if not impossible to prevent, therefore, a requirement is needed from an airframe viewpoint to deal with the problem as it exists and to establish appropriate structural degradation limits.

REQUIREMENT GUIDANCE (A.3.2.24 through 3.2.24.4)

Provide appropriate foreign object damage requirements and structural degradation limits. For birds and hail impacts, the requirements may be stated in terms of the expected number of impacts of selected sizes of birds and hail being equal to the volume of air swept-out by the projected frontal area of the component for discrete mission segments of all air vehicles times the expected average number of selected birds or hail per volume of air, summed over all discrete mission segments. For air vehicles involving low risk to personnel and small impact on the overall program even if structural damage does occur due to bird or hail impact, a lesser requirement may suffice. Such lesser requirements could be stated in terms of arbitrary sized bird and hail impacting at some arbitrary velocity. Structural degradation limits should be stated in terms of man-hours required to repair or replace damaged components and that no impact will cause injury to personnel, with or without attendant structural damage. For bird impact information, see lessons learned. For hail size, see MIL-STD-210. The runway debris requirement should be made applicable only if the air vehicle configuration, structure, type of runway and surface conditions warrant it. A requirement may exist for operating on wet surfaces or surfaces of loose gravel where structure behind the tires could be impinged upon by water or stones causing damage, including finish erosion, dents, cracks, voids and

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delaminations. The structural degradation limits for runway debris must be compatible with the requirements. Include other sources, for example, airframe fasteners shed during mission or maintenance tools left in critical airframe bays or areas and define the acceptable airframe degradation permitted for each encounter.

The maximum acceptable frequency of loss of the air vehicle or the incapacitation of the crew due to FOD impact is 1×10^{-7} per flight. The number selected should be consistent with the rate defined in 3.2.11. The maximum acceptable frequency of occurrence of FOD impacts which would cause unacceptable damage to the air vehicle is generally 1×10^{-5} per flight for air vehicles built with metallic structures. This specification of a frequency of occurrence is directly related to the type of damage defined in the subparagraphs. The selection of both frequencies is normally based on peace-time usage. However, the frequency distribution for FOD damage may change during actual war usage. Such changes need to be addressed to ensure that FOD damage during war does not cause unacceptable reductions in the war fighting capabilities.

The specification in the subparagraphs of the type or size of FOD should be based on the expected peace-time usage. As with the selection of the frequencies discussed above, the type and size of FOD may change during actual war usage. Such changes need to be addressed to ensure that FOD damage during war does not cause unacceptable reductions in the war fighting capabilities.

The specification in the subparagraphs of the type or level of damage which is unacceptable is intended to distinguish between damage which does not have any significant mission impact and whose burden of repair is acceptable and damage which significantly impacts mission capabilities or has a high economic burden for repair. Some types of structural elements may be able to tolerate some damage with no significant reductions in performance or in mission capabilities. Other types of structural elements may not be able to tolerate any detectable damage. The selection of the type and level of unacceptable damage should address such considerations as the cost of repairing FOD damage, the length of time to institute the repair, the facilities required to make the repair, the degradation of the structural life due to unrepaired damage, and the reduction of mission capabilities due to unrepaired FOD damage.

REQUIREMENT LESSONS LEARNED (A.3.2.24 through 3.2.24.4)

Bird strikes. Over a two year reporting period, 1 Apr 1978 to 31 Mar 1980, there were 3,258 reports submitted of bird strikes with USAF aircraft. Fortunately, no crashes or fatalities occurred; however, 5.775 million dollars worth of damage resulted. Once a bird strike occurs, there is a one in six chance that the strike will cause damage. During the 12 years before October 1980, seven military pilots were killed and 14 aircraft destroyed because of bird strikes. Birds are suspected in several other aircraft crashes as well. Commercial aviation records show that within the past decade there have been 29 civil registered aircraft destroyed and 14 fatal accidents where bird strikes were a factor. During the last seven years, bird strikes have resulted in the destruction of jet transport and executive aircraft at the rate of one and one-half per year. During 1978, there were 36 reports submitted to FAA detailing bird strike damage to aircraft ranging from windshield penetration to the fatal crash of a Convair 580. These aircraft had passenger loads ranging from two to 265 people. Most strikes occur at or near airports, either on takeoff or landing and below 3,000 feet AGL. An April 1976 study indicated that 51 percent of the reported bird strikes occurred within five miles of the airfield. Recent data (Apr 78-Mar 80) show this figure to be 46.6 percent. Bird strikes by phase of flight are shown on figure 7. The highest impact was at an altitude of 14,000 feet and the lowest was an aircraft holding for takeoff. The first 500 feet of altitude is where the greatest hazard of bird strike exists. The chance of hitting a bird dramatically increases below 300 feet AGL and dramatically decreases above 3,000 feet AGL.

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The months of April and May have a higher incidence of bird strikes than the norm. The rate decreases slightly during the summer months, June through August. Then, it rises dramatically in September, October, and November, with October being the peak month having over twice as many reported bird strikes as any other month of the year. The potential for bird strike disaster reaches its peak as waterfowl, weighing as much as 15 pounds each, move South into their winter habitat. The greatest movement of waterfowl is along four primary routes: the Atlantic, Mississippi, Central, and Pacific flyways. Because of their size and large numbers, ducks, geese, and cranes present the greatest hazard. These hazardous species of birds are preceded by migratory song birds. The smaller birds have been involved in serious mishaps, but generally they cause minimal damage.

Bird strikes by impact area on airframe are shown on figure 8. Of the 20.4 percent of bird strikes which impacted windshields and canopies, only seven percent of these resulted in shattered transparencies. The other category includes bird strikes on the landing gear, vertical and horizontal stabilizers, flaps, fuselage, and ordnance. Bird strikes by type of aircraft are shown on figure 9.

If numerous flocks of small birds are encountered, it is probable that gaggles of much larger waterfowl will soon follow. An increase in small bird impacts found on post flight inspections aid in identifying those operations which entail the greater risk from birds. If operations are on or near one of the four main migratory flyways or if requirements are to perform flight into these areas, there are positive steps which can be taken to lessen the hazard. Limit night flights during October and November. If numerous small bird impacts are experienced, curtail night flying for approximately one week to allow these small bird flocks to exit the local area. They transit an area quickly and quite often at night. Flights below 10,000 feet AGL should be kept to a minimum because most migratory activity occurs between 1,500 feet and 5,000 feet AGL. Airspeed below 10,000 feet AGL should be kept as low as practical. Landing lights should be displayed below 10,000 feet AGL to assist in bird avoidance. If birds are encountered, the aircraft should climb since bird distribution diminishes with altitude; also, it has been determined that birds in flight that are startled or feel threatened, instinctively dive.

Use of low-level routes should be scheduled between 0900 and 1500 daily because waterfowl activity is at a minimum during this time. Preference should be given to routes with an East-West orientation to further reduce exposure, and route segments that fly over bodies of water should be avoided. Visors should be worn by the pilots at all times during flight below 10,000 feet AGL, and the windshield should be heated to improve bird resistance. Low-level mission briefings during September, October, and November should include bird encounters and actions to be taken in the event of a bird strike which may result in serious injury to the pilot or loss of cockpit communications. Local, state, and federal wildlife officials are the best source of information on local bird movements. Flyway data have been published in various documents, and this information can be procured from region offices of the US Fish and Wildlife Service at the US Department of the Interior.

Swing wing bomber: Foreign object damage due to bird strike is of particular concern for an aircraft required to perform low level terrain following of avoidance flight. The windshield and supporting structure was designed to withstand impact of a four pound bird at the low level penetration speed without spalling of the transparency inner surface.

Swing wing fighter/bomber: Nose erosion of external tanks requires replacement of the forward 1/3 of the tanks for problems confined to a couple of square inches. Many man-hours are required to remove/replace the nose portion of the external tanks. Thirty percent of tank replacements are for this reason. The nose cones of the external fuel tanks are single piece components, some six feet long. The very tip of the nose erodes away due to airflow, dust

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particles, etc. and gives rise to fuel leaks. No repair of the tip is authorized; therefore, the whole nose cone must be replaced.

Swing wing fighter/bomber: An engine experienced substantial damage due to ingestion of blind rivet components. Local investigation revealed several discrepancies, including lack of training and rivet guns not in proper working order or calibration. MS 33522 (rivets for blind attachment, limitations for design and usage) prohibits use of blind rivets around jet engines in locations where loosened rivet components could fall or be drawn into engine air inlets. This military standard has been in effect since 1972. The above aircraft and several others existed prior to publication of MS 33522.

Attack/fighter: The operation units reported numerous incidents of items being dropped in the cockpit. Many of these items wind up in the area under the ejection seat. This area contains control cables and other components. An item lost in the cockpit creates a recognized unsafe condition and must be removed prior to releasing the aircraft for flight. The operation units expend numerous man-hours searching for items dropped by air crew or maintenance personnel. The condition can be eliminated by covering the area under the ejection seat. In fact, all Navy aircraft of this type conform to a time compliance technical order which covers this area.

Attack/fighter: The aileron rudder interconnect (ARI) is a component in the automatic flight controls system. The ARI transducer is located on the uppercenter line of the aircraft fuselage, directly above an opening to and around the engine cavity. If any tool or nut/bolt is dropped (and this is a common event), a tedious attempt to fish the item out of the cavity is necessary. If this process is unsuccessful, then the engine must be removed to retrieve the dropped item.

Impact damage susceptibility: There are certain areas of an aircraft that are subject to high intensity impacts and a high frequency of occurrences. The components in these areas must be designed to withstand the impacts that the component will see during its service life. Thin-skinned components (which are either advanced composite or aluminum) and honeycomb components (which are covered by thin skins of advanced composite or aluminum) are susceptible to impact damage when placed into service. The impact damage to these structures is causing significant maintenance requirements. Honeycomb consists of a thin-skinned outer layer covering a honeycomb structured interior. The outer skin can consist of metal or advanced composite material. Damage to honeycomb parts occurs from skin punctures as well as core crushing. In a majority of instances, impacts to honeycomb structure cause a separation between the skin and the core, thus the skin is not supported. Metal skins are less susceptible to punctures because of their capability to plastically deform, but they are nevertheless susceptible. An impact to a metal skin will cause a dent, misshape the metal, and possibly crush the core material. Advanced composite skins consist of fibers, usually boron or graphite, embedded into an epoxy or polyamide resin. The structural rigidity of the composite skin is based on the direction of the fibers by providing strength in the direction in which they are lying. Because of the properties of advanced composite material, plastic deformation will not occur in a composite skin as it does in a metal. A comparable impact to a composite skin will most probably break the fibers and puncture the skin. Thin-skinned components that are not attached to honeycomb are also susceptible to impact damage in the same manner as described for honeycomb skins.

Heavy air/ground fighter: Mission was a low level sortie flown at 480 knots and 500 feet AGL. The pilot saw a shadow followed immediately by impact. There was a loud noise and jolt as the bird entered the cockpit followed by a loud buzzing and an increase in noise level and vibration. The bird hit the landing gear handle causing the gear to extend, struck the pilot in the left arm, chest, and helmet and continued aft knocking off the rear cockpit mirror. The bird struck the

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WSO in the helmet. The bird and the mirror came to rest lodged in the banana links of the rear cockpit ejection seat. The WSO took control of the aircraft, began a climb and slowed down so cockpit communications could be regained. This procedure was briefed in the pre-mission briefing. The pilot was able to take control after he made an assessment of the damages. The left front quarter panel was missing; the front windscreen was shattered. Most of the instruments on the left side of the panel were either missing or broken and unusable and most of the front canopy was covered with blood, flesh, and feathers. After intercockpit communications were reestablished and the pilot took control, he declared an emergency and requested a chase aircraft to check his gear. The gear indicated down and locked and this was confirmed by the chase. Aircraft made a successful landing. Investigation revealed a bird was also ingested in the Number 1 engine, causing damage to the CSD housing and minor damage to the engine.

Heavy air/ground fighter: The aircraft collided with a large bird. The bird entered the front cockpit through the left windshield side panel and struck the front seater in the chest and face. The pilot was left semiconscious but with fatal injuries. The front seater initiated a dual ejection. The pilot was a fatality and the aircraft was destroyed on impact.

Swing wing fighter: A bird strike resulted in airframe damage and engine FOD. Post flight inspection revealed bird remains inside left engine intake and engine. Damage from bird strike consisted of two exterior panels under wing glove, fiberglass panel inside engine intake and extensive damage to engine. A small piece of metal (1/4 x 1/4 inch) from one panel was found laying inside the engine after burner aft section. The engine was removed and shipped to depot.

Very large transport: Shortly after takeoff, the aircraft experienced unusual sounds and light vibrations for a period of less than five seconds. During the preflight the next day, damaged second stage fan blades were discovered in the number three engine. The damaged engine was returned to its home station for inspection and repair. Inspection of the engine revealed bird remnants on the first stage stators and the second stage stator vanes. Further inspection revealed five second stage blades and one second stage stator spacer were cracked and bent.

Very large transport: During climbout from a touch and go training mission, the aircraft struck a flock of ducks. After impact, the aircraft experienced vibrations from number one engine. The engine was reduced to idle and an emergency declared. After landing, inspection revealed number one engine had large hunks of outboard portions of the first and second stage fan blades missing. The fan cowling had rub damage from the broken fan blades. Number two engine had one bird strike, but no damage.

Navigation trainer: During landing, the aircraft encountered a flock of large birds, which upon impact jarred the aircraft. Immediately, severe vibrations were noted from number one engine. The tower noted sparks from the engine and immediately cleared the aircraft for landing. The engine was shut down and an uneventful single engine landing was accomplished. The preliminary investigation revealed number one engine air intake and the right stabilizer were dented. The inlet guide vanes, compressor, stator, and turbine blades were also damaged.

Very large transport: During a short final landing, the aircraft encountered a flock of seagulls. An uneventful landing was accomplished. The preliminary investigation revealed number one, three, and four engines were struck as well as the wing leading edge, wing flaps, and radome.

Transport: Severe wind and hail damage to two aircraft at Chicago O'Hare Airport.

Air supremacy fighter: Following an air intercept mission, the aircraft boarding ladder steps were noted to be extended approximately 18 inches. The straight-in approach was flown and a

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landing was accomplished. During post-flight inspection, major FOD to the left engine was discovered.

Subsonic trainer and ground attack: Two aircraft were damaged by hail in separate episodes but with a common thread. Each expected Air Traffic Control to pass a warning. The trainer got some dents in the leading edge of the wing. The pilot was briefed of isolated thunderstorms enroute. After descent to 15,000 feet for penetration, the aircraft entered clouds with no turbulence encountered. After about 45 seconds hail and rain hit the aircraft and continued for 20 seconds. The pilot reported he was not advised either by Center or Approach Control of any heavy weather or hail. The ground attack was more severely damaged with both intake ducts, vertical stab, strobe lights, and nose cone receiving hits. The weather briefing indicated an isolated storm far north of the route that should not be a factor. No weather was forecast at flight planned altitude. The flight leaped off, the IP assuming that Center would keep him notified of any severe weather. The flight entered an embedded thunderstorm and ran into hail. Air traffic controllers have limited capability to identify hazardous weather and are not required to routinely offer weather avoidance assistance.

Ground attack: Foreign objects (general) - Foreign objects can either be hard or soft, metallic or non-metallic, large or small, externally or internally hazardous, and either introduced or self-generated in the aircraft. With specific regard to flight control systems, MIL-F-9490 (see Fouling prevention) states that all elements of the flight control system shall be designed and suitably protected to resist jamming by foreign objects. In principle, the best approach to solving foreign object intrusion problems is to prevent foreign objects from being generated. However, this is idealistic, and every designer of equipment or systems should assume that foreign objects will exist and should design the equipment or system to be invulnerable to foreign object intrusion. For flight systems which are exposed to combat threats, foreign objects may be in the form of fragments (as a result of a bullet/missile hit) and equipment or systems should be designed with this in mind as a survivability enhancement. The aircraft was designed to survive extensive in-flight battle damage, but the flight control system in particular was found to have a number of close clearances vulnerable to foreign object jamming and the Special Review Team has recommended changes to improve that situation. The recommended changes are being documented in the Review Team final report currently in preparation.

Ground attack: Foreign object sources - There are probably many thousands of possible sources of foreign objects in any aircraft if one considers that every fastener, rivet, pin, nut, and bolt can be a foreign object when it is not in its proper place. Two of the most probable reasons for such an object not to be in its place are: (1) failure of the object to be retained because of a breakage or malfunction; and (2) human error - improper installation or oversight. Of these two probabilities, human error is by far the most likely reason. The data base on foreign object incidents/accidents almost always identifies that the suspect object was an unattached fastener or other part which was not broken, and frequently shows the foreign object to be a tool or some other item needed for assembly, maintenance, or repair which had been left in the aircraft. In a ground attack program, the statistics show an average of only one piece of foreign object matter being found in every five aircraft undergoing Air Force Initial Receiving Inspection and this is an excellent record. However, after the aircraft has been in field operations and maintenance for a few years, there are records showing that several pieces of foreign object matter exist in every aircraft inspected. As a consequence, for several of the aircraft which crashed for unknown reasons and when the pilot was also fatally injured, the accident investigating boards invariably list a flight control system jam (implying a foreign object jam) as one of the possible primary causes.

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The ground attack aircraft design features a ballistic foam, often referred to as void filler foam, which is in a block form and fitted into the cavities of the fuselage and wing root just external to the fuel tanks. This ballistic foam is intended to improve the survivability of the aircraft against fires/explosion caused by a bullet/missile fragment puncturing a fuel tank. The foam has been noted to be one of the primary sources of soft foreign objects and one fatal crash is suspected to have been caused by a loose piece of the foam migrating between the aileron bellcrank and an adjacent bulkhead. Although unconfirmed, the possibility exists that soft foreign objects such as loose foam can restrict motion of the flight control system until the soft object is dislodged, crushed, or cut-through. Changes are being implemented to improve the adhesion of the foam, to shape the foam blocks to minimize breakage, to protect the exposed surfaces/corners with a durable coating/mesh, and to improve instructions in the maintenance manuals on how to avoid damage to foam when performing maintenance in the region.

Ground attack: Migration paths - Once a foreign object is generated within an aircraft, maneuvering of the aircraft, vibration, and landing jolts will cause the foreign object to move around. In most aircraft, the bulkheads and frames will have openings to allow wire bundles or cables to pass through and may have cut-outs for weight reduction purposes. Every opening must be regarded as a migration path for a foreign object to take, and the probability must be assessed with many factors considered (i.e., the size/shape of the opening and the relative size/shape of the foreign object, the location of the opening, the maneuvering accelerations and orientations which can be commanded by the pilot, the presence of equipment items which may act as baffles, etc.). Further, as the foreign object migrates along probable paths, one must assess whether there are any critical components (e.g., a flight control system bellcrank) which can be adversely affected by the foreign object. To this writer's knowledge, there are no situations where a foreign object has ever improved the operation of a system, therefore, only two assessments are possible - the foreign object will either be detrimental or have no effect.

Prior to recent improvements, the ground attack aircraft was found to be designed with a highly probable and hazardous migration path. In tracing the cause for one in-flight flight control system jam followed by an emergency it was found that a Tridail fastener used as an access panel support rod pin had fallen into a forward avionics compartment, bounced through a bulkhead opening, fell into the U-shaped fuselage longeron, traveled the length (about 10 feet) of the longeron, and lodged in the lower part of the aileron bellcrank causing a temporary jam. Improvements being made include the blocking of the last bulkhead openings above the fuselage trough, placing a barrier in and above the trough to block migration of loose foam and hard foreign objects from upstream into the bellcrank region, and a design for more positive retention of the access panel support rod end pin.

Ground attack: Clearances - The flight control system specification, MIL-F-9490, reflects the allowable clearances within the flight control system to insure that no probable combinations of temperature effects, air, loads, structural deflections, vibrations, build-up of manufacturing tolerances, or wear can cause binding or jamming of any portion of the control system. The minimum allowable clearances vary from 1/8 inch to 1/2 inch depending on the region/function (see MIL-F-9490 paragraph on System separation, protection, and clearance) and reflect the lessons learned from problems experienced in earlier flight vehicles. At the start of the production program, waivers to these clearances were requested by the contractor and granted by the Government; in retrospect, this reduction in clearances was probably an economically correct decision but may have over-looked the increase in probability for having flight control system jams due to foreign object intrusion. The Special Review Team has identified areas where small clearances cause a high potential for jam due to foreign object intrusion and changes are being made to install covers over some of these small clearance areas or to add barriers in the potential migration paths into the region of the small clearance.

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Ground attack: Manufacturing/assembly - During the manufacture and assembly of every aircraft, there exists a very high potential for foreign objects to be introduced into the aircraft. This is due to many different people working with many different tools and having to install many fasteners and other small parts in the aircraft. The Air Force Regulation 66-33 covering foreign object prevention is normally incorporated in every aircraft acquisition contract and manufacturers add to the regulation their special documents governing how their Manufacturing, Assembly and Quality Assurance Departments will implement their Foreign Object Prevention Program. In addition, the DPRO (resident Government plant representative) will assign Quality Assurance inspectors to assure that the foreign object prevention program is being implemented as planned. The crucial ingredient in any foreign object prevention program is the people who perform the manufacturing, the assembly, and the inspections - and how well they have developed their attitude and discipline towards producing a foreign object free product.

The Special Review Team reviewed the program and operations at both divisions (where the manufacturing and partial assembly is done and where the final assembly and testing is done prior to delivery to the Air Force). In summary, a good program for foreign object prevention was found and needed only a renewal of emphasis plus some minor changes to assure consistency between the two divisions. Management elected to shift the responsibility for their Foreign Object Prevention Program from their Quality Assurance Department to their Manufacturing/Assembly Department. This was based on the logic that it is better to have the activity that is most probably the generator of foreign objects (i.e., manufacturing and assembly) be responsible for keeping the foreign objects out than to rely on the quality assurance inspectors to find and remove the foreign objects. QA will still perform their inspections and the AFPRO QA will still inspect and sign off on each compartment as it is closed during final assembly.

Ground attack: Maintenance/modification - Once an aircraft has been delivered to the Air Force, it is exposed to numerous maintenance actions and to occasional modification actions. This presents the opportunity for foreign objects to be generated in the aircraft principally because it involves many people, many tools and many loose fasteners and other parts. In fact, the opportunity is increased because maintenance is often required to be performed in a more exposed environment and under poorer lighting conditions than exists on a typical manufacturing/assembly line. Another factor is that the experience of blue suit maintenance personnel is generally much less than that of the manufacturer's work force and it is common that the maintenance manuals are not written as clearly as they might be. Although this is not a unique problem, the Special Review Team has found that the maintenance manuals are generated by engineers and reviewed by more experienced Air Force senior NCOs with very little involvement by the lower grade maintenance people who have to ultimately interpret and apply the instructions.

The number of foreign objects being found in ground attack aircraft is in a decreasing trend but the Special Review Team maintains a concern that there are a lot of aircraft flying with foreign objects in them. The Maintenance Working Group has caused improvements to be made in the maintenance manuals and also has caused a buddy system of maintenance to be done at bases whenever a foreign object sensitive area is opened up for maintenance and repair. These improvements, coupled with the addition of the changes described earlier (barriers, covers, better adhesion, etc.), should greatly reduce the generation of foreign object and the system vulnerability to them. However, it is again emphasized that the effectiveness of a good foreign object prevention program is very dependent on the attitude and discipline of the people performing the maintenance. Carelessness breeds foreign objects.

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Ground attack: Protective measures - Because humans always have the potential to make a mistake, because an aircraft such as this one has some areas/systems which are vulnerable to foreign object intrusion, and because a flight control jam can be catastrophic if it occurs during a maneuver near the ground, protective measures must be taken to assure that the system does not suffer a jam for any reason. Small clearances are conducive to jams (e.g., a Tridair fastener head diameter is 1/2 inch and the aileron bellcrank clearance in the fuselage trough is between 1/4 and 3/8 inch); relying on humans to not generate foreign objects is insufficient protection. A cover can be added over the region where a small clearance exists but care must be exercised that the cover itself or the means by which it is attached does not become a source of foreign objects. Care should also be exercised that the cover be complete because if an opening in the cover is large enough to allow foreign objects to enter the region, the cover may perform just opposite to its intent (i.e., it will keep the foreign object in rather than keeping it out) and increase the probability for a jam. The Special Review Team has recommended that the aileron bellcrank with the small clearance be covered, but if that is impractical, then some form of a sweep be added at the bottom of the bellcrank to deflect foreign objects approaching the region.

A.4.2.24 Foreign object damage (FOD). (___)

Analyses shall be used to verify that the airframe structure complies with the foreign object damage requirements of 3.2.24. Testing shall be required as appropriate.

VERIFICATION RATIONALE (A.4.2.24)

Verification of the adequacy of the airframe to withstand foreign object impingement is necessary to assure that the air vehicle performance will not be degraded or that unacceptable unscheduled maintenance down-time does not arise when impacts with foreign objects do occur.

VERIFICATION GUIDANCE (A.4.2.24)

VERIFICATION LESSONS LEARNED (A.4.2.24)

A.3.2.25 Producibility.

Producibility must be designed into the aircraft structure from the beginning and must be a design influence throughout the design process.

REQUIREMENT RATIONALE (A.3.2.25)

REQUIREMENT GUIDANCE (A.3.2.25)

REQUIREMENT LESSONS LEARNED (A.3.2.25)

A.4.2.25 Producibility.

It must be demonstrated that manufacturing is an integral part of the design process. Producibility demonstrations are required for new or unproven design, construction, or manufacturing concepts to minimize the production risk. Producibility should be a factor in structural design trade studies.

VERIFICATION RATIONALE (A.4.2.25)

VERIFICATION GUIDANCE (A.4.2.25)

VERIFICATION LESSONS LEARNED (A.4.2.25)

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A.3.2.26 Maintainability.

Maintainability must be designed into the aircraft from the beginning and must be a design influence throughout the design process. The maintainability shall be consistent with the user's planned operational use, maintenance concepts, and force management program. High or moderate maintenance items must be accessible and/or replaceable to facilitate maintenance.

REQUIREMENT RATIONALE (A.3.2.26)

REQUIREMENT GUIDANCE (A.3.2.26)

REQUIREMENT LESSONS LEARNED (A.3.2.26)

A.4.2.26 Maintainability.

It must be demonstrated that maintainability is an integral part of the design process. Maintainability demonstrations are required for new or unproven designs, construction, or material systems to minimize the maintenance risk. Maintainability should be a factor in structural design trade studies.

VERIFICATION RATIONALE (A.4.2.26)

VERIFICATION GUIDANCE (A.4.2.26)

VERIFICATION LESSONS LEARNED (A.4.2.26)

A.3.2.27 Supportability.

Supportability must be designed into the aircraft structure from the beginning and must be a design influence throughout the design process. Supportability shall be consistent with the user's present and projected maintenance concepts, maintenance facilities, and force management programs. Projected EPA requirements must be considered.

REQUIREMENT RATIONALE (A.3.2.27)

REQUIREMENT GUIDANCE (A.3.2.27)

REQUIREMENT LESSONS LEARNED (A.3.2.27)

A.4.2.27 Supportability.

It must be demonstrated that supportability is an integral part of the design process. Supportability demonstrations are required for new or unproven designs, construction, or material systems to minimize the supportability risk. Supportability should be a factor in structural design trade studies.

VERIFICATION RATIONALE (A.4.2.27)

VERIFICATION GUIDANCE (A.4.2.27)

VERIFICATION LESSONS LEARNED (A.4.2.27)

A.3.2.28 Repairability.

Repairability must be designed into the aircraft from the beginning and must be a design influence throughout the design process. Repairability is required to support production, maintain the fleet, and maximize operational readiness by repairing battle damage. High or moderate maintenance items and items subject to wear must be repairable.

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REQUIREMENT RATIONALE (A.3.2.28)

REQUIREMENT GUIDANCE (A.3.2.28)

REQUIREMENT LESSONS LEARNED (A.3.2.28)

A.4.2.28 Repairability.

It must be demonstrated that repairability is an integral part of the design process. Structural repair manuals are required by the user to maintain and support the aircraft. Repairability demonstrations are required for new or unproven designs, construction, or material systems to minimize the support risk. Items subject to wear must be able to accommodate refurbishment or repairs such as oversize bushings or fasteners. Repairability should be a factor in structural design trade studies.

VERIFICATION RATIONALE (A.4.2.28)

VERIFICATION GUIDANCE (A.4.2.28)

VERIFICATION LESSONS LEARNED (A.4.2.28)

A.3.2.29 Replaceability/interchangeability.

Appropriate levels of replaceability and/or interchangeability must be designed into the aircraft structure to meet the requirements of operational readiness, maintenance, supportability, logistic concepts, repairability, and producibility. Major structural items which are interchangeable are ______________________.

REQUIREMENT RATIONALE (A.3.2.29)

REQUIREMENT GUIDANCE (A.3.2.29)

REQUIREMENT LESSONS LEARNED (A.3.2.29)

A.4.2.29 Replaceability/interchangeability.

Interfaces must be identified and controlled on replaceable and/or interchangeable parts. Interchangeable parts must be documented and interchangeability verified by demonstration. The impact on replaceability/interchangeability must be evaluated as a factor in structural design trade studies.

VERIFICATION RATIONALE (A.4.2.29)

VERIFICATION GUIDANCE (A.4.2.29)

VERIFICATION LESSONS LEARNED (A.4.2.29)

A.3.2.30 Cost effective design.

Cost effective design concepts and practices must be used from the beginning of the aircraft design and must be a design influence throughout the design process. Balancing acquisition cost, life cycle cost, performance, and schedule is an integral part of an integrated product development concept. An integrated design approach which strives for a producible cost effective design is critical to achieving the optimal balance of design, life cycle cost, schedule, and performance. A stable design with stable processes is required for accurate cost assessments.

REQUIREMENT RATIONALE (A.3.2.30)

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REQUIREMENT GUIDANCE (A.3.2.30)

REQUIREMENT LESSONS LEARNED (A.3.2.30)

A.4.2.30 Cost effective design.

The airframe should be designed to cost using allocated cost requirements from higher level specifications. Design trades should be made against these allocated costs or a reallocation of costs considering acquisition cost and life cycle cost. A stable design and process is required to minimize the cost assessment risk.

VERIFICATION RATIONALE (A.4.2.30)

VERIFICATION GUIDANCE (4.2.30)

VERIFICATION LESSONS LEARNED (A.4.2.30)

A.3.3 Specific design and construction parameters.

The following specific features, conditions and parameters, marked applicable, reflect required operational and maintenance capability of the airframe. These items have a service life, maintainability, or inspection requirement different than the parent airframe as identified in 3.2.14. Historical maintainability experience with the same, or similar, design and construction shall be a governing factor for suitability of the airframe design.

REQUIREMENT RATIONALE (A.3.3)

If the structural integrity of the airframe is not adequate to safely react the loads induced during a required maneuver, the airframe is clearly deficient. However, if a little used item like a tail bumper does not adequately protect the aft end of the airframe during tail down landings, it may not be identified as being deficient until many airframes have been built and a considerable number of service hours have been accumulated. Therefore, these specific hardware requirements are needed to assure that requirements for selected components are established, particularly those components and requirements not covered by the overall airframe requirement.

REQUIREMENT GUIDANCE (A.3.3)

This requirement addresses those cases of criteria where the individual components and subsystems are directly involved with the operational and maintenance needs of the user. The criteria is unique to particular components and subsystems and as such the inherent relationship between the hardware and the desired performance needs must be maintained.

REQUIREMENT LESSONS LEARNED (A.3.3)

Modification management - AFLC/AFALD, (1981). Aircraft modification is a double-edged sword. It offers the Air Force a means to improve aircraft safety, maintainability, and mission accomplishment, and can add significant new capabilities. At the same time, poor planning can aggravate minor deficiencies and can even lead to the introduction of new deficiencies. For the modification process to work efficiently, communication must occur between the designer, user, and supporter of the equipment. Those responsible for a modification need to determine (1) the original design intent, (2) weight/space/power and other limitations of the aircraft, and (3) impact of the modification on system supportability. Undesirable side effects are likely to result from a modification when those proposing the change have not considered the original design intent. This type of oversight occurred on one aircraft when a switch was modified for the sake of standardization. The pilot's overhead control panel in this aircraft cockpit contains four fuel

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and start switches (one for each engine) and one switch for applying continuous ignition to all engines. As a human factors feature, the original design engineer had chosen a different shape for the handle of the continuous ignition switch. This precaution was intended to let the pilot know by touch that he had indeed selected the correct switch when he placed the continuous ignition switch to the off position following level-off. By inadvertently selecting one of the fuel and start switches, the pilot shuts down an engine. Such a mistake creates an obvious flight hazard and it means an almost certain unplanned descent to achieve air start parameters. Mistakes of this kind were uncommon until a modification was accepted to use only one type of switch and eliminate the other from the inventory. When an incident occurred (an engine was shut down inadvertently at level-off), the safety risk was deemed serious enough to warrant a quick fix. A second modification was needed to undo the damage caused by the first. Even when a modification is well-conceived, failure to consider the demands of the modification upon the existing systems, in terms of weight, space, power, air conditioning, computer capacity, etc., can result in a system deficiency, inoperable equipment, or a safety hazard. A modification to install a flight history recorder in one Air Force aircraft required power beyond the capacity of the existing inverter. While this inverter was adequate for the original configuration of the aircraft, growth of power requirements had already reached maximum inverter capacity. The flight history recorder was installed, but it could not be operated due to lack of power. Finally, modifications can impair supportability and access to other equipment. Although this problem cannot always be avoided, the supportability problems are sometimes so extreme that they outweigh any benefits from the modification. On one aircraft, a modification eliminates access to the drain valve for the auxiliary fuel tank. Access to this valve is needed to facilitate defueling. The consequences of the modification induced inaccessibility is that whenever an auxiliary tank has to be defueled, it is necessary to drain the fuel through a pogo valve. This method takes many hours and requires that a maintenance technician hold the valve open throughout the defueling. Many other instances exist of a modification creating supportability problems in aircraft. These examples are not indicative of the many beneficial aspects of the Air Force Modification Program.

A.4.3 Specific design and construction parameters.

Inspections, analyses, and tests as noted below shall verify that the airframe structure complies with the design and construction requirements of 3.3.

VERIFICATION RATIONALE (A.4.3)

These verification tasks are needed to show that the selected hardware components do in fact perform as required and possess sufficient structural integrity to perform as required as often as required.

VERIFICATION GUIDANCE (A.4.3)

Deciding which requirements are to be verified by analyses and which ones are to be verified by tests or both must be accomplished with care. Showing by test that the airframe can satisfactorily withstand the occurrences of all potential and likely failures from which recovery is expected could be very expensive, hence the verification would probably be primarily by analyses. Similarly, not verifying the capability of the arresting hook by test could also be very expensive and testing probably would be the primary means of verification. Each verification task needs to be determined and established on the merits of the requirements.

VERIFICATION LESSONS LEARNED (A.4.3)

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A.3.3.1 Doors and panels. (____)

The structural integrity of doors and panels, including seals shall be sufficient for their intended use, including that resulting from the air vehicle usage of 3.2.14. The use of any door/panel panel shall not be inhibited by interference with other parts of the air vehicle or require special positioning of the air vehicle or any part thereof during normal use. For ground maintenance, all doors/panels shall be fully usable with the landing gear struts in any position. The door/panel cut-out support structure shall meet the in-flight residual strength requirements of 3.12.2.

REQUIREMENT RATIONALE (A.3.3.1)

Access into airframe compartments, both large and small, has long been a necessity. However, the consequences are not readily apparent regarding the placement and motions of doors and panels during use under all attainable operational and maintenance conditions. This requirement is needed to promote the consideration, evaluation, and avoidance of such ramifications regarding airframe doors, including structural panels when applicable.

REQUIREMENT GUIDANCE (A.3.3.1)

As needed, the requirement can be expanded to include structural panels and their associated operational requirements.

REQUIREMENT LESSONS LEARNED (A.3.3.1)

Swing wing fighter bomber: This series of aircraft incorporate large access panels and doors (over 20 sq. ft.). When the aircraft came out of production, the engine bay access doors could be opened and closed by hand with minimal effort. These doors are opened daily for inspection and maintenance purposes. Repeated opening/closing actions have worn the alignment pins and locking mechanism. This, coupled with small structural deformation as the aircraft ages, has caused extreme difficulty in maintaining gap tolerances and aerodynamic smoothness requirements. Alignment pins and locking mechanisms are inspected, repaired, and adjusted during isochronal (ISO) inspections to the extent possible.

Transport: The cargo doors are sealed using a combination of methods, including a rubber flap which is sealed by the pressure placed on it and a pliable bead or strip of sealing material at the point of contact between the door edge and aircraft structure. This bead must be of uniform thickness and remain pliable to be an effective seal. The current seal material hardens with age and requires constant maintenance to retain pressurization. The rubber flap also tends to harden with age and lose its sealing ability.

Very large transport: The crew entry door/ladder is being overstressed during use. When several crew members or maintenance personnel climb up the ladder with their suit cases or tool boxes, excessive stress is applied to the mounting point at the fuselage, since the ladder is not supported at the other end. A recent modification has been initiated to provide an extension to the ladder by adding two rods with small wheels that will extend from the ladder to the ground. This will minimize the cantilever stresses in the door mount. In addition, the hydraulic system used to activate the crew entry door is highly complex requiring many man-hours to rig and adjust.

Transport: Trooper door tracks are a part of the basic structure and require about 125 man-hours to replace. Field units recommend tracks not be made a part of the aircraft basic structure. Further investigation reveals the door tracks have approximately 15 years of life. Door reliability prior to onset of wearout is very good. A weight penalty and additional inspections would most likely be required if tracks were not part of basic structure. Therefore, it appears the current design of the tracks is the best trade-off. A possible improvement of the

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door system would be quickly replaceable rollers with sacrificial wear properties to further extend the life of the tracks.

A.4.3.1 Doors and panels. (___)

Preliminary and final drawings shall contain sufficient detail to show that all doors are fully usable for all applicable operational and maintenance conditions in compliance with the requirements of 3.3.1. Tests shall show compliance with the clearance requirements of 3.3.1. Damage tolerance analyses and tests shall verify that the damage tolerance requirements of 3.3.1 are met.

VERIFICATION RATIONALE (A.4.3.1)

Verification that all doors and panels perform as required by 3.3.1 is needed to show that the air vehicle can perform its operational missions and maintenance objectives as intended.

VERIFICATION GUIDANCE (A.4.3.1)

VERIFICATION LESSONS LEARNED (A.4.3.1)

A.3.3.1.1 Access doors and components. (___)

Access doors and components with one or more quick-opening latches or fasteners shall not fail, open, vibrate, flap, or flutter in flight with ___________________________. This requirement also applies to structural doors and panels. The most critical combinations of latches or fasteners are to be designed for left unsecure conditions.

REQUIREMENT RATIONALE (A.3.3.1.1)

The requirement is intended to keep access doors from opening in-flight and becoming damaged from being torn free from the airframe and becoming FOD.

REQUIREMENT GUIDANCE (A.3.3.1.1)

Small as well as large external access doors need to be inherently stable when subjected to attainable air flows with one or more retaining devices fully nonfunctioning. Doors with one or two latches need to have the hinge located so that the air flow will tend to keep the door closed. The second blank is to be filled with the number of latches or fasteners per door or panel that can be left unsecured. Recommend filling in the blank with the cube root (rounded off) of the total number of latches or fasteners per door or panel.

REQUIREMENT LESSONS LEARNED (A.3.3.1.1)

A.4.3.1.1 Access doors and components. (___)

Analyses and tests shall verify that access doors and components meet the requirements of 3.3.1.1.

VERIFICATION RATIONALE (A.4.3.1.1)

Verification that all access doors and components perform as required by 3.3.1.1 is needed to ensure that the air vehicle can safely perform its operational missions as intended.

VERIFICATION GUIDANCE (A.4.3.1.1)

VERIFICATION LESSONS LEARNED (A.4.3.1.1)

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A.3.3.2 Doors and ramps mechanisms of pressurized compartments. (___)

The latching mechanisms used on doors and ramps shall not be capable of indicating closed and locked and the air vehicle pressurized if any part of the latching mechanism or associated structure is not performing its intended function. Visual inspection of each latch, for proper closure and locking shall be provided on doors and ramps using two or more latches per operating mechanism or control. Doors and ramps mechanisms, including hinges, locks and stops, shall meet the damage tolerance requirements for fail-safe multiple load path structure of 3.12.2.2.

REQUIREMENT RATIONALE (A.3.3.2)

These latching mechanisms are the heart of the retention systems for doors and ramps, a requirement is needed to assure that the mechanisms are performing this retention function properly.

REQUIREMENT GUIDANCE (A.3.3.2)

If the paragraph is applicable, insert APP in the blank; if not applicable, insert N/A. See also the specification on doors and ramps mechanisms.

REQUIREMENT LESSONS LEARNED (A.3.3.2)

Very large transport: The forward ramp lock system on the aircraft consists of two rows of ganged hook locks on the starboard and port side of the forward fuselage. Each row contains four hooks on bellcranks attached to tie rods that are connected in series and are activated by a single hydraulic actuator. The aft ramp lock system is similar to the forward ramp except each row contains seven hooks. In both the forward and aft ramp floor, the floor brackets and the tie rods frequently have to be repaired or replaced because of breakage or corrosion, after which the whole assembly must be re-rigged. A potentially dangerous condition arises when either a rigging error is made, a single lock fails or a tie rod breaks causing the direction of pressure applied to the tie rods to shift 180 degrees and could cause several hooks to unhook from the floor bracket allowing the cargo compartment pressure to push out the cargo ramp resulting in a possible ramp failure if it happened in flight.

Very large transport: The forward cargo door and ramp system on the aircraft consists of a visor that is also the forward pressure vessel structure when closed. The visor latching and locking mechanism consists of twenty-five hydraulic bayonet locks and sixteen over-center hooks and yoke pin combination latches. They are located around the periphery of the visor and ramp. Mechanical lock indicators are provided on twenty-three of the hydraulically actuated bayonet locks. Limit switches on each lock are connected into the door lock warning system. When the visor lock hydraulic actuator pushes the tapered pin into the cone shaped receptacle, it activates a switch that turns off a light in the cockpit and it also pushes a cable that is part of the mechanical lock indicator device. The cable on the opposite end of the mechanical lock indicator is marked with graduated red stripes and protrudes from the sleeve to indicate the degree of locking accomplished. The inaccurate readings of the indicators are caused by: the weakening of the spring in the sleeve that keeps tension on the cable, the jamming of the cable in the sleeve, and the bending of the brackets that attach the mechanical indicator to the bulkhead. If the indicator on the cable is erratic, the flight crew will not accept it and abort the flight, when in reality a positive lock was accomplished when the light in the panel was turned off. Any crew or maintenance personnel can look at the lock pin and visually determine if a good positive lock was achieved.

Transport: Aft cargo door actuating cylinders now in use are equipped with a rod end bearing which has a lubricating hole in the outer shell. Certain holes may weaken the rod end assembly

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causing failures. A new rod end bearing assembly that does not incorporate this hole has been developed. This modification will replace the earlier bearings with the new assembly.

A.4.3.2 Doors and ramps mechanisms of pressurized compartments. (___)

Preliminary and final drawings shall show the details of the latching mechanisms and the means whereby the indicating and operating requirements of 3.3.2 are met. Analyses and tests shall show compliance with the latching and non-latching requirements of 3.3.2. Damage tolerance analyses and tests shall verify that the damage tolerance requirements of 3.3.2 are met.

VERIFICATION RATIONALE (A.4.3.2)

Verification that door and ramp mechanisms operate as required by 3.3.3 is necessary to show that operational and maintenance objectives and missions will not be compromised nor air vehicles lost due to non-operating or damaged mechanisms.

VERIFICATION GUIDANCE (A.4.3.2)

VERIFICATION LESSONS LEARNED (A.4.3.2)

A.3.3.3 Ramps. (___)

Deflections, deformations, and motions of any ramp shall not interfere with other parts or components of the air vehicle during normal use of the ramp and air vehicle. Ramps shall meet the in-flight residual strength requirements of 3.12.2.

A.3.3.3.1 Engine inlet ramps or equivalent compression surfaces. (___)

Water shall not collect or be trapped in these ramps during flight or ground use such that ice can form and damage the ramp or subsequently shed into the flight control surfaces or engines causing damage to the surfaces or engine.

A.3.3.3.2 Cargo ramps - loading and unloading. (___)

Any ramp used for loading or unloading of cargo defined in 3.2.2 shall be capable of sustaining all vertical, lateral, and longitudinal loads from initial contact, alignment, and traverse of the ramp by the cargo. The cargo shall contact the ramp:

a. At speeds up to ___________.

b. At any horizontal angle to the ramp within + ________ degrees.

c. And align with and traverse the ramp at speeds up to __________.

A.3.3.3.3 Cargo ramps - inflight. (___)

Any ramp used to support cargo in-flight shall ______________.

REQUIREMENT RATIONALE (A.3.3.3)

These particular ramp requirements are necessary to assure that pertinent details of usage are reflected adequately in the airframe.

REQUIREMENT GUIDANCE (A.3.3.3)

If 3.3.3.b is applicable, provide the appropriate values of ramp maximum contact speed, horizontal angle, and maximum traversing speed. If 3.3.3.c is applicable, provide a definition of

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the cargo and pertinent operating conditions. For example, any ramp used to support cargo in-flight shall sustain the ground and flight usage loads of the cargo defined in 3.2.2. Such usage includes load cresting at the ramp/cargo floor/intersection raising and lowering of the ramp when loaded, carriage of cargo on the ramp up and locked, rapidly off-loading palletized with the cargo compartment, jettisoning of airdrop cargo at a "-g" condition, and towing a drogue parachute at airdrop speeds. Jettison of airdrop cargo is a malfunctioned or emergency condition that must be considered for each airdrop cargo regardless of position within the aircraft at some minimum (.25 g in the past) ejection condition. Some airdrop modes could require the towing of a drogue chute that transmits a load to the ramp via a force transfer mechanism on or in the ramp. The maximum parachute force or conditions to determine this force must be provided.

REQUIREMENT LESSONS LEARNED (A.3.3.3)

Large transport: The maximum cresting limit is 20,000 pounds with the ramp down. Due to this limit some cargo which have concentrated loads exceeding 20,000 pounds during cresting must be loaded with the cargo ramp coplanar with the floor. This is a tactical disadvantage for cargo aircraft.

A.4.3.3 Ramps. (___)

Analyses and tests shall verify that ramps comply with the requirements of 3.3.3.

VERIFICATION RATIONALE (A.4.3.3)

Verification that the ramps perform as required by 3.3.3 is needed to show that operational and maintenance use of the air vehicle will not be degraded.

VERIFICATION GUIDANCE (A.4.3.3)

VERIFICATION LESSONS LEARNED (A.4.3.3)

A.3.3.4 Cargo floors. (___)

Cargo floors shall be capable of supporting cargo distributions of _________.

REQUIREMENT RATIONALE (A.3.3.4)

Requiring the air vehicle to carry a specified total amount of cargo is necessary but not sufficient when considering cargo floors. Density and attainable distributions of the cargo are also significant.

REQUIREMENT GUIDANCE (A.3.3.4)

Define or include figures that define maximum applicable cargo distributions. Cargo such as bulk cargo, wheeled vehicles, tracked vehicles, palletized cargo, and airdrop cargo, each present unique cargo distributions. Bulk cargo distributions are normally defined in terms of pounds per linear foot and pounds per square inch (psi). Wheeled vehicle distributions are normally defined in terms of axle weight for single axles and dual axles with axles spaced a minimum distance apart, wheel loading normally a minimum of one-half axle weight, tire loading and concentrated off treadway loading. Tracked vehicle distributions are normally defined in terms of pounds per linear foot and unit loading. Where the air vehicle has hardened floor areas, known as treadways, to withstand the wheeled and tracked vehicle load distributions, the width of the treadway should be large enough for any possible side-by-side vehicle positioning within the cargo compartment. Palletized logistic and airdrop cargo distributions are normally defined in terms of roller limits, pounds per linear foot of conveyor, and pounds per lateral row of rollers. The palletized logistic cargo handling system may not necessarily be the same as

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the airdrop cargo handling system. When either cargo handling system is required to be an alternate mission kit, the loading distribution of the cargo transferred through the cargo handling system to the cargo floor should be specified. The lateral location of roller conveyors should interface with the airdrop platforms, adapter pallets, etc., specified in 3.2.2. For example, the cargo compartment floor shall be capable of supporting cargo distribution of single axle loads of __________ pounds and dual axle loads of __________ pounds each at 42 inches between bogey axles and tracked vehicle running loads of __________ pounds per linear foot for up to __________ feet at all lateral and longitudinal locations dictated by center of gravity (c.g.) considerations for unit loads of this weight or lateral displacement of tread sizes for vehicles of this magnitude. All other areas of the cargo floor shall have a minimum capacity of pounds axle loads and __________ pounds per foot running loads. The floor capacity shall permit drive-on loading and air transport without shoring of 1/2-inch or less may be used only as required to prevent steel from contacting the floor surface. Each logistic conveyor roller shall provide a capacity of __________ pounds when rollers are spaced 10 inches on center (fore and aft). For a spacing of other than 10 inches, an equivalent load design shall be provided. The equivalent lateral row capacity shall not be less than __________ pounds for any two rollers in the same lateral row. Total load capacity per linear foot of conveyor shall not be less than __________ pounds per foot. Each airdrop conveyor roller shall provide a capacity of __________ pounds when the rollers are 10 inches on center (fore and aft) with an equivalent lateral row capacity not less than __________ pounds for any two rollers in the same row. Total capacity per linear foot of conveyor shall be commensurate with the aircraft floor. Provisions in the cargo floor for restraint of the cargo are to be identified in terms of alternate loading, dimensions, and arrangements based upon trade studies. Current air vehicle tiedown provisions have 10,000 pound and 25,000 pound capabilities, capable of interfacing with the MB-1 and CGU-2A, and MB-2 tiedown assemblies, respectively. The cargo floor tiedown provisions are the subject of international standardization agreements. When any tiedown arrangement, size, or load capability affects or violates the international agreement concerned, the preparing activity will take appropriate reconciliation action through international standardization channels including departmental standardization offices, if required.

REQUIREMENT LESSONS LEARNED (A.3.3.4)

Very large transport: CSAF message 051818Z Nov 69 initiated standardization of the lateral location of the roller conveyors per the location of the very large transport logistic roller conveyors nominally 13.9 and 41.6 inches from the centerline to insure proper interface with airdrop platforms and forklift tines.

Large transport: The cargo floor and integral cargo handling system was designed for uniform loading of the airdrop platform; i.e., weight divided by the size of the platform. The airdrop roller loads were recorded in 1969. The results of the test program indicated that the roller load distributions were not uniform, and that aircraft tolerances, energy dissipating material, and cargo weight distribution affect the roller loads.

Transport: A large supply of lumber is required for moving rolling stock. For instance, a large Army tank needs many sheets of 3/4-inch plywood for shoring and protection of the cargo floor and rails. This lesson may not be applicable to all cargo aircraft. On the aircraft that have the problem, the cargo rails were added to the aircraft and bolted to the floor. This makes it necessary to use 3/4-inch plywood between the rails for shoring and more plywood over the top of the rails to provide for proper weight distribution. Some cargo aircraft have rails that flip up out of the way or retract into the floor. This enables the out-sized equipment to sit directly on the treadway.

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Transport: Installed (removable kit) cargo rails have many deep crevices and cavities which catch a great deal of debris. It is not practical to hose out the interior, although that would be a preferred solution. A large transport has cargo rails that are flush and, as a result, easy to clean.

A.4.3.4 Cargo floors. (___)

Analyses and tests shall verify that cargo floors comply with the requirements of 3.3.4.

VERIFICATION RATIONALE (A.4.3.4)

Verification is needed showing that the cargo floors will sustain the cargo distributions of 3.3.4 so that operationally required cargo missions can be flown successfully.

VERIFICATION GUIDANCE (A.4.3.4)

VERIFICATION LESSONS LEARNED (A.4.3.4)

A.3.3.5 Transparencies. (___)

The structural design of the following transparencies shall permit replacement of the transparencies within the man-hours indicated: __________________.

REQUIREMENT RATIONALE (A.3.3.5)

The time and effort required to replace a transparency is a function of the airframe and transparency interface structure and sealing (if necessary) technique used. Some form in place gaskets and potting compounds possess very long cure times. The minimum time and effort that can be allowed for this action needs to be established for the airframe in this requirement.

REQUIREMENT GUIDANCE (A.3.3.5)

Define those transparencies (windshields, sensor or camera ports, etc.) which if damaged (scratched, delaminated, broken, etc.) could prevent the successful performance of required missions. For each of these transparencies, list the maximum number of maintenance man-hours and total elapsed time that can be allowed for replacement of each transparency.

REQUIREMENT LESSONS LEARNED (A.3.3.5)

Air supremacy fighter: After two or three opening/closing cycles of the canopy, the accumulator that opens the canopy is depleted. On the fighter-trainer configuration this does not result in a problem because there is a hand pump to open the canopy. However, the A model does not have this feature; therefore, the maintenance technician has to stand on the aft inlet, which is frequently covered with moisture, and open the canopy by hand. This is time consuming and hazardous because of the awkward position and poor footing.

Very large transport: This transport has many flight deck windshields and windows. Cracks and delamination resulting from mechanical damage, improper heat application, and environmental conditions are principle causes for many replacements annually. Originally wet sealant was used for windshield installations because it was thought the windshield frames were not flat and smooth enough for dry seal gasket. After installation, the wet sealant normally requires 10 to 24 hours for cure time before the aircraft can be flown. On the transport a set sealant installation was used until it was established that a suitable flat surface could be provided on the forward windshield frames to accommodate use of a dry seal gasket. It was also noted that the gasket from a smaller transport pilot's and copilot's windshields would work on the much larger transport. Dry seal gaskets are only used on the side window panels. Wet sealant is still used to install the left hand (LH) and right hand (RH) side window panels; a

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silicone sealant that requires eight hours to cure is used to seal LH and RH clear vision panel openings. The dry seal gaskets need a silicone sealant between the gasket and the glass which requires 24 hours to 72 hours cure time; however, the gasket can be cemented to the glass and cured up prior to a windshield replacement requirement. With a dry gasket, the aircraft is ready to fly within two hours after installation; a short cure time is required for the light faying surface coat put on the gasket and the aerodynamic gap filler used around the outside. Higher manufacturing costs may be a factor because of the tighter tolerances required to provide structural flatness for a dry seal and also meet aerodynamic flatness requirements.

Ground attack: The windshield is raised in order to perform maintenance. The windshield will often deform due to thermal expansion to such a degree that it can no longer be secured. Thermal deformation is an unavoidable characteristic of the windshield material. The ANG used a jig which prevented the windshield from spreading when it was raised. The factory uses a similar jig.

Heavy air/ground fighter: Two mishaps have occurred involving canopy loss, inadvertent drogue chute deployment and fatalities to the rear cockpit crew member. From 1965 through 1979, the Air Force has had 161 reported canopy losses and the Navy and Marines have had 188 canopy losses. There have been no incidents where the drogue chute deployed as it has in the two recent Class A mishaps. The windblast force on the drogue chute lanyard with the dummy has been measured to be 2 pounds maximum and without the dummy the force was 6 pounds maximum. An aircraft canopy was jettisoned with the dummy installed. The maximum force on the lanyard was 8 pounds and there were no detrimental effects on the drogue chute container or the dummy. The conclusion was that within the scope of this test, the windblast in the aft cockpit during canopy loss does not present a hazard.

Heavy air/ground fighter: Mishap recommendation requested rear canopy rigging procedures be changed to include a chart specifying the different bolt lengths required, dependent on the number of shims installed. Subsequently, alternate bolts have been identified for use in appropriate hinge location.

Attack/fighter: Canopy retention redesign effort initially provided for improved hooks, rod end, over center links, and electrically operated central locking bellcrank and an improved design canopy acrylic. A subsequent study has shown that the canopy loss rate is no greater than similar AF aircraft; however, they still supported the safety of flight classification. The risk assessment indicates that without any modification the aircraft will lose a canopy assembly in-flight every 91,743 flight hours and an aircraft loss will ensue as a result of this loss every 3,853,206 flight hours.

Supersonic trainer: Forward canopy panel blew out and departed aircraft. Failure was attributed to crazing fissure at the top rear of panel not detectable by visual inspection. Indications are that the fissure has progressed over a period of 200 - 300 flying hours before occurrence.

A.4.3.5 Transparencies. (___)

Analyses and tests using full scale representative articles of transparencies shall verify the replacement times of 3.3.5.

VERIFICATION RATIONALE (A.4.3.5)

Verification that the transparencies can be replaced within the man-hour and time constraints of 3.3.5 is necessary to show that this operational and maintenance need is met.

VERIFICATION GUIDANCE (A.4.3.5)

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VERIFICATION LESSONS LEARNED (A.4.3.5)

A.3.3.6 Tail bumper. (___)

A tail bumper shall be provided.

a. Type: _______________.

b. Capability: ______________.

REQUIREMENT RATIONALE (A.3.3.6)

This requirement is aimed at projecting the empennage from damage during ground usage when the brakes are applied while the air vehicle is rolling backwards or the air vehicle is over-rotated on take-off or landing, or during shipboard towing operations for all allowable sea state conditions.

REQUIREMENT GUIDANCE (A.3.3.6)

Define the type and capability required. The type of tail bumper may be active (energy absorbing) or passive, retractable or fixed, and with or without provisions for a replacement shoe. The capability of the tail bumper may be minimum, used only to discern if it contacted the ground during take-offs and landings. The capability may be intermediate, with sufficient energy absorption to withstand ground tip backs at specified rearward velocities and ground slopes and to withstand ground contacts during take-offs and landings but change the pitch altitude only slightly. The capability may be full, with sufficient energy absorption to withstand contact with the ground during any take-off and landing and change the pitch altitude sufficiently to prevent damage to the airframe or other air vehicle system. For a modification program, the need and applicability of this requirement will be known. However, for a new program, full empennage protection should be required and if the developer can show that a lesser tail bumper requirement is adequate for his particular airframe, a reduction can be considered at that time.

REQUIREMENT LESSONS LEARNED (A.3.3.6)

A.4.3.6 Tail bumper. (___)

Analyses and tests shall verify that the tail bumper has the capability to perform as required by 3.3.6.

VERIFICATION RATIONALE (A.4.3.6)

Verification that the tail bumper performs as required by 3.3.6 is needed to show that the air vehicle will not be damaged by conditions of 3.3.6 capability, up to which the tail bumper must be able to satisfactorily perform.

VERIFICATION GUIDANCE (A.4.3.6)

VERIFICATION LESSONS LEARNED (A.4.3.6)

During normal carrier operations, aircraft with aft c.g. tip back angles less than 20° have exhibited unacceptable ship compatibility.

A.3.3.7 Tail hook. (___)

A tail hook shall be provided.

a. Type of hook and shoe: _________________________.

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b. Type of engagements: ________________________.

c. Arrestment system and cable: ________________________.

d. Surface in front of arrestment cable: ________________________.

e. Capability: ________________________.

REQUIREMENT RATIONALE (A.3.3.7)

A tail hook is desirable for those air vehicles whose weights and ground speeds are within the capabilities of ground based arresting systems because it can contribute to minimizing damage due to emergency landings, including landing of combat damaged air vehicles, or if needed, to operating off of very short runways. A tailhook is a requirement for carrier operations.

REQUIREMENT GUIDANCE (A.3.3.7)

Define the remaining requirements. See 3.2.14 for general service life usage requirements regarding number of arrestments, etc. The type of hook and shoe may be emergency (non-retractable from the cockpit) with or without a replaceable shoe or it may be operational (retractable from the cockpit) with a replaceable shoe. The type of engagements may be take-off abort, landing, but in-flight cable pick-up, landing impact/roll-out cable pick-up or any combination thereof. The arrestment system and cable needs to be defined as to energy absorbing capability and cable size and height above runway through use of figures or applicable technical document references. The surface in front of arrestment cable is to be defined regarding any roughness which could cause the hook to bounce over the cable. The capability of the tail hook assembly is to be defined in terms of successfully withstanding engagements up to the capacity of the arrestment system and cable as limited by the operational parameters of the air vehicle for the condition, for example gross weight, center of gravity, speed, and pitch and yaw attitudes. Define the number of feet away from the centerline of the runway, out to which barrier engagements are expected to be made.

REQUIREMENT LESSONS LEARNED (A.3.3.7)

Swing wing fighter bomber: The major wear on the tail hook assembly occurs in the shoe. The shoe is an integral part of the tail hook assembly, and the whole assembly must be removed when the shoe is worn. This causes expensive part replacement. Other USAF and Navy aircraft have tail hooks with replaceable shoes.

Air Supremacy Fighter: Tactical Air Force Using Commands and especially the Alaskan Air Command, are requesting frequent use of the arresting hook for training and icy runway landings, for engine run-up operations and for simulated damaged runway exercises. Air Force organizations, using two other aircraft in tactical operations, have developed operational landing tactics requiring continual use of the arresting hooks. These arresting hooks are stressed for continuous use. Reasonable engineering analyses indicate that the subject tail hook should be limited to emergency use only. To modify the aircraft to perform routine arrested landings is feasible but requires extensive redesign, analyses, and tests.

Air supremacy fighter: The aircraft was returning to its home station when a utility circuit "A" hydraulic failure light illuminated. Aircraft was diverted to an alternate base for recovery because of weather. Aircraft failed to engage barrier for unknown reason and departed end of runway.

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A.4.3.7 Tail hook. (___)

Dynamic analyses shall show that the tail hook will function as required by 3.3.7. Tests shall verify that the tail hook will engage the arrestment cable, perform as required, and meet the requirements of 3.3.7.

VERIFICATION RATIONALE (A.4.3.7)

Verification that the tail hook can arrest the air vehicle satisfactorily per the requirements of 3.3.7 is needed to minimize the potential of damage to the air vehicle during emergency landings and short field landings where the use of an available arresting barrier is desired by the user.

VERIFICATION GUIDANCE (A.4.3.7)

For carrier based aircraft, the arresting hook verification test requirements are per paragraph 3.20, Carrier suitability demonstration tests, and table 6 of MIL-D-8708B plus the requirements of BIS (Board of Inspection and Survey).

VERIFICATION LESSONS LEARNED (A.4.3.7)

A.3.3.8 Vents and louvers. (____)

If necessary to maintain their required usefulness, equipment and structure behind and near vents and louvers shall be designed for the effects of flow through the vents and louvers during conditions of normal and reverse flows. Thermal, sand abrasion, rain, ice, etc. foreign object damage effects are to be covered for _______________.

REQUIREMENT RATIONALE (A.3.3.8)

Hot gases from auxiliary power units as well as from propulsion systems may be drawn into the airframe through vents and louvers under some conditions thus damaging equipment and structure.

REQUIREMENT GUIDANCE (A.3.3.8)

Recommend inserting in the blank the following words: one lifetime of usage of 3.2.14.

REQUIREMENT LESSONS LEARNED (A.3.3.8)

Light air/ground fighter: A mishap report recommended the horizontal tail operating mechanism be redesigned to better protect the horizontal tail operating mechanism from loss due to flight fire and that the Engine Bay Keel area be modified to prevent the possibility of a common airflow path to both engines in the event of an engine bay fire.

A.4.3.8 Vents and louvers. (___)

Analyses and tests of gas temperatures and airflows through vents and louvers onto equipment and structure behind and near vents and louvers shall verify that the requirements of 3.3.8 are met.

VERIFICATION RATIONALE (A.4.3.8)

Verification that gas temperatures and air flows through vents and louvers under all conditions are not detrimental to equipment and structure in the area is needed so as to not degrade the mission capability or to increase the maintenance time of the air vehicle.

VERIFICATION GUIDANCE (A.4.3.8)

VERIFICATION LESSONS LEARNED (A.4.3.8)

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A.3.3.9 Cavities. (___)

Structures, equipment, and equipment provisions in, adjacent to, or immediately downstream of cavities open to the airstream during flight shall be designed for the effects of oscillatory air forces. Pressure oscillations within and downstream of the cavity shall be minimized by addition of airflow control devices.

REQUIREMENT RATIONALE (A.3.3.9)

Air flow past cavities induces oscillatory air flows and pressures in and downstream of cavities open to the airstream. Structures, equipment, and equipment provisions which are in the cavity, in areas adjacent to the cavity, or in areas downstream of the cavity are exposed to high level oscillating forces and vibrations. Airflow control devices such as spoilers can ameliorate the most destructive portions of these pressure fluctuations known as cavity resonance. However, high level, wide frequency band, random oscillations will occur in any case. The requirement is to minimize the problem and to design structures and equipment to withstand the resulting environment.

REQUIREMENT GUIDANCE (A.3.3.9)

REQUIREMENT LESSONS LEARNED (A.3.3.9)

High level pressure fluctuations, including cavity resonance, are found in all bays open to an airflow across the opening. Oscillatory frequencies of these fluctuations are associated with the bay dimensions while pressure amplitudes are associated with flight dynamic pressure. Various flow control devices, typically spoilers, can be used to control the cavity resonance portion of the fluctuations.

A large bomber aircraft experienced high oscillatory loads in structures, doors, and equipment in and around weapons bays when weapons bay doors were opened in flight. Subsequent investigation revealed that weapons bay cavity resonance was driving these loads. A weapons bay spoiler was added to the aircraft which resulted in high but acceptable loads in the forward and mid weapons bays. The aft weapons bay was improved but still experiences dynamic loadings too severe for some payloads.

Another large bomber was developed using the lessons learned as discussed above. Wind tunnel tests and analyses were used to design weapons bay spoilers which resulted in high level but acceptable dynamic environments in the weapons bays.

A.4.3.9 Cavities. (___)

The details of the protection of equipment and equipment provisions in cavities shall be shown on preliminary and final drawings. Analyses and tests shall verify that the requirements of 3.3.9 are met.

VERIFICATION RATIONALE (A.4.3.9)

Verification that the airflow induced pressure fluctuations within, adjacent to, and downstream of cavities will not harm structures, equipment, or equipment provisions is needed to assure that the air vehicle will be able to perform as required by the user.

VERIFICATION GUIDANCE (A.4.3.9)

VERIFICATION LESSONS LEARNED (A.4.3.9)

A large bomber was developed using wind tunnel tests and analyses to design weapons bay spoilers. This resulted in eliminating cavity resonance as a significant factor. Note however

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that high level broad band random dynamic environments still existed in and behind open weapons bays.

A.3.3.10 Armor. (___)

Armor shall be provided to _____________.

REQUIREMENT RATIONALE (A.3.3.10)

Close support and other combat air vehicles may need to have the crew and other critical components protected to minimize loss of the air vehicle due to hits from enemy projectiles and warhead fragments.

REQUIREMENT GUIDANCE (A.3.3.10)

Define the equipment, components, crew, etc. that the armor is to protect, as well as the threats it is to protect against. Reference to 3.9 or applicable subparagraphs thereof, may be appropriate.

REQUIREMENT LESSONS LEARNED (A.3.3.10)

A.4.3.10 Armor. (___)

Details of the location and amount of armor shall be shown on preliminary and final drawings. Analyses and tests shall verify that the requirements of 3.3.10 are met.

VERIFICATION RATIONALE (A.4.3.10)

Verification that the armor protects the crew and air vehicle as required by 3.3.10 is needed to assure that the air vehicle can perform its required combat missions repeatedly.

VERIFICATION GUIDANCE (A.4.3.10)

VERIFICATION LESSONS LEARNED (A.4.3.10)

A.3.3.11 Refueling provisions. (___)

The area around the aerial refueling receptacle or aerial refueling probe system shall be free of obstructions and shall not need to be replaced for ________________.

REQUIREMENT RATIONALE (A.3.3.11)

Aerial refueling may be a requirement of the user to extend the range of mission time on station and if so this requirement is needed from an airframe viewpoint.

REQUIREMENT GUIDANCE (A.3.3.11)

Define the amount of service usage that the structure around the receptacle must withstand regarding refueling and refueling impacts. This service usage is to be compatible with usage of the air vehicle and be a measurable quantity relatable to the number of refuelings using the receptacle.

REQUIREMENT LESSONS LEARNED (A.3.3.11)

Aerial refueling obstructions. During flight testing of a prototype, a UHF antenna was located approximately 2 feet behind the aerial refueling receptacle. This antenna was relocated because of boomer complaints. During full scale development, a TACAN antenna was located 46 inches forward of the aerial refueling receptacle and was subsequently moved to a location

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36 inches forward of the receptacle. Operational experience has shown that this clearance is not sufficient since several TACAN antennas have been damaged during refueling.

A.4.3.11 Refueling provisions. (___)

Preliminary and final drawings shall show that the required area around the aerial refueling receptacles or aerial refueling probe system is free of obstructions. Analyses, inspections, and tests shall verify that adequate clearance, strength, and impact durability exists for the structure in the area around the refueling receptacle in compliance with the requirements of 3.3.11.

VERIFICATION RATIONALE (A.4.3.11)

Verification that the refueling provisions of airframe are adequate is needed so that the structure will not be damaged during refueling causing abort of that mission as well as cancellation of follow-on missions due to maintenance time required to repair the airframe.

VERIFICATION GUIDANCE (A.4.3.11)

VERIFICATION LESSONS LEARNED (A.4.3.11)

A.3.3.12 Cables and pushrods. (____)

Cables and pushrods shall meet the following requirements: ________________________.

REQUIREMENT RATIONALE (A.3.3.12)

Cables are sometimes used for controlling aerodynamic surfaces and other devices as well as in some special cases they are used in structural applications. This requirement is needed to address any and all airframe and airframe related cables as necessary.

REQUIREMENT GUIDANCE (A.3.3.12)

Identify any special cables and the requirements. For other cables, provide the applicable requirements or reference applicable portions of military specifications for aircraft cables (see MIL-W-87161).

REQUIREMENT LESSONS LEARNED (A.3.3.12)

Swing wing fighter bomber: The construction of the throttle cables includes a thin metal push-pull ribbon which operates on and is supported by ball bearings along its entire length. The cable is a high-failure item because the bearings are not tolerant of grit, dirt, or water. The cable is easily damaged during installation because it will tolerate bending in one plane only. Removal and replacement of the cable requires 12 man-hours after all panels are removed. The cable cannot be fed or fished through conduits or pulleys. The clamps securing the cables are brittle plastic and are easily broken. The same cable is used for wing sweep, flap/slot systems. The apparent reason for using this type of cable is its very low friction limit. This cable works well in a controlled environment area, but it is not suitable for flight line use. Cable design/selection should take both operational and maintenance hazards into account. Friction limits should be considered very carefully to insure realistic requirements. The cables should be designed to prevent the entrance of debris and also have the capability of flexing 360 degrees to ease installation.

Subsonic trainer: Before maintenance tasks can be performed in some areas, the cables must be disconnected. A barrel type of turnbuckle with both a left and right-hand thread is used whereby disconnecting destroys the tension adjustment. Moreover, an accessibility problem further complicates adjustment and rigging of the aileron control cables. Two turnbuckles for adjusting cable tension are located in each wing root. These turnbuckles require safety wiring -

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a task that is virtually impossible because of limited space and because the cables are so close together. As a result, it takes maintenance personnel four to five hours just to adjust aileron rigging tension. Quick-disconnect turnbuckles, such as those used on the supersonic trainer aircraft, are trouble-free, do not require safety wiring, and do not require that tension adjustments and tests be performed after reconnection.

Transport: Throttle cable breakage has been a problem since 1966. Fatigue tests and experience on other aircraft indicate that the installation of nylon jackets will extend cable life sufficiently to effectively prevent further cable breakage. The following actions have been taken:

a. Increased frequency of cable inspection requirement.

b. Improved method of cable inspection to include use of eddy current testing.

c. Issued Time Compliance Technical Order (TCTO) to inspect throttle tension regulators.

d. Issued TCTO to inspect and replace undampened cable tension regulators with the improved dampened regulators.

e. Revised Programmed Depot Maintenance (PDM) Requirement to replace all throttle and condition cables from the throttle quadrant to the engine nacelle and every second PDM thereafter.

f. Proposed Class IVA Modification to install propeller flight idle stop to prevent propeller reversal in flight, if an increase power throttle cable breaks. This proposal has been approved by USAF.

g. Redesign has incorporated new cables and larger pulleys.

Air superiority fighter: During a routine training flight, the aircraft experienced a rapid loss of thrust. A restart attempt was unsuccessful. Pilot safely ejected and the aircraft crashed. During the accident investigation of the aircraft and engine, it was revealed that the rear compressor variable vane push pull control (cable) was broken. Two interim immediate action TCTOs were issued for a one time inspection of rear compressor variable vane, synchronizing arm bearing and push pull control (cable) for binding and security. Results of this inspection replaced 11 synchronizing arms and push pull control cable assemblies for binding. Four of these synchronizing arm and control cable assemblies were sent to the engine contractor for investigation and analysis. Results of investigation revealed failure was caused by chrome spalling of synchronizing arm bearing, causing seizure of synchronizing arm and breaking of push pull control cable by undue stress. Result of investigation determined that chrome spalling was caused by bearing staking procedures and fit tolerance of bearing in synchronizing arm. Retrofit of the fleet is scheduled to install a new Teflon coated bearing with revised staking procedures. Inspection of synchronizing arm bearing and cable every 10 flight hours will continue until retrofit is complete.

A.4.3.12 Cables and pushrods. (___)

Analyses, inspections, and tests shall verify that the requirements of 3.3.12 are met.

VERIFICATION RATIONALE (A.4.3.12)

Verification of the structural adequacy of all airframe cables is necessary to show that the air vehicle will perform as required by the user and that unscheduled maintenance down-time will not occur due to broken or deficient airframe cables.

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VERIFICATION GUIDANCE (A.4.3.12)

VERIFICATION LESSONS LEARNED (A.4.3.12)

A.3.3.13 Airframe bearings and pulleys. (____)

Airframe bearings and pulleys shall meet the following requirements: _______________.

REQUIREMENT RATIONALE (A.3.3.13)

Airframe bearings are used in air vehicles to provide supports for components which move with angular motions. Pulleys are similarly used to change the direction of cables. This requirement is needed to assure that adequate structural integrity exists when they are incorporated into and are a part of the airframe.

REQUIREMENT GUIDANCE (A.3.3.13)

Identify any special bearings and pulleys and the requirements. For other bearings or pulleys, provide the applicable requirements or reference applicable portions of military specifications for aircraft bearings, such as MIL-STD-1599 and AFSC DH 2-l, Chapters 3 and 6. For pulleys see MIL-P-7034.

REQUIREMENT LESSONS LEARNED (A.3.3.13)

Very large transport: Fabric lined bearings are used throughout the aircraft. In some cases, the bearings proved reliable and trouble-free. However, when subjected to environmental conditions that include dirt, water, and hydraulic contamination; the bearing liner swelled, then chafed/frayed and failed. The replacement of the liner is expensive and difficult. The Main Landing Gear Yoke Liner replacement cost is $150 every two years. At four per aircraft with 77 aircraft, annual cost for this item is $23,100. Some liners cannot be replaced. An example would be the monoball bearings used in 12 locations. The failure/replacement rate is two per year per aircraft at $400 each; annual cost is $61,600.

Navigation trainer: Commercial operators of this basic aircraft have found severely worn forward engine mount outboard lug bearings with indication of lug contact with the mating link assembly clevis. This proposed modification requires inspection of fittings for cracks, replace the bearing in the outboard lug of each engine forward mount, machine the link assembly for additional clearance, and assemble with a new bolt torqued to a reduced value.

A.4.3.13 Airframe bearings and pulleys. (___)

Analyses, inspections, and tests shall verify that the requirements of 3.3.13 are met.

VERIFICATION RATIONALE (A.4.3.13)

Verification that all airframe bearings and pulleys will meet the requirements of 3.3.13 is needed to assure that the air vehicle components which depend on bearings and pulleys will perform smoothly and that the bearings and pulleys will not fail or malfunction causing abort of the mission or an increase in unscheduled maintenance down-time.

VERIFICATION GUIDANCE (A.4.3.13)

VERIFICATION LESSONS LEARNED (A.4.3.13)

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A.3.3.14 Fasteners. (____)

Fastener selection, installation, quality assurance (including screw threads and screw thread quality verification techniques), and joining methods shall be commensurate with the specified airframe operational and support requirements.

REQUIREMENT RATIONALE (A.3.3.14)

An air vehicle and airframe are only as good as the fasteners which hold them together. This requirement is needed to assure that all fasteners used in the airframe possess adequate structural integrity.

REQUIREMENT GUIDANCE (A.3.3.14)

The requirements should be stated such that the performance of the fastened assembly is the prime consideration in the designer's selection of fasteners. Maintainability and supportability aspects should be included along with appropriate reference to an integration with the strength, stiffness, durability, damage tolerance, and corrosion requirements of this specification. Requirements should consider the application of the fastener in the design. If it is used in assembling critical elements or components, the fastener requirements should be clearly related to controls imposed for the design, manufacture, installation, maintenance, and service monitoring of the critical elements or components. MIL-STD-1515, AFSC DH 1-2, and MIL-STD-1568 are three good sources of data from which requirements may be derived. MIL-STD-1515 and MIL-STD-1568 should not be imposed in their entirety as they contain very specific, directive wording which would probably limit the designer's approach to meeting fastener requirements. However, these documents should be carefully studied as many of their requirements identify standard practices and convey lessons learned.

REQUIREMENT LESSONS LEARNED (A.3.3.14)

Swing wing fighter: Number two engine encountered FOD during flight. Aircrew didn't notice any significant engine problems during the mission. Postflight inspection of the aircraft revealed a missing sleeve bolt fastener on panel 1101. Impact marks in the engine matched with the fastener. The 27TFW FOD monitor found a bad floating nutplate for the fastener. The jaws on the shank failed to properly hold the fastener retaining bolt. Vibration allowed the fastener to back out of nutplate and be ingested by the engine.

Ground attack: During the post flight inspection FOD damage was discovered to the left engine. Post flight inspection revealed a fastener from a panel located on the fuselage below the boarding ladder came loose in flight, hit the left leading edge slat and bounced into the left engine intake. The fastener that came loose was the incorrect size for the panel. The correct size fastener has not been available through supply channels. At an unknown time, the wrong size fastener was installed in the panel.

Fastener recess design: The maintenance technician frequently cannot position himself where he can apply sufficient pressure to hold the removal tool in place in order to remove the hi-torque screws used in the access panels. The removal tool cannot be properly inserted in the fastener recess and usually results in the recess being routed out or damage being done to the surrounding structure. Although the use of improper procedures may cause such problems, the technician is also restricted by the limited access, instability, and position of the work stands. The fastener system for removable access panels needs to be compatible with the maintenance environment.

Swing wing fighter bomber: Threaded fasteners which have different grip lengths should not be used on the same panel. When an access panel is attached by various grip length fasteners, maintenance technicians often do not know which fastener fits in which hole. As a result of this

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confusion, the technician frequently installs the wrong length fastener. This causes one of two problems. Either the attaching hardware (i.e. nutplate or domenut) is damaged because the fastener is too long or attachment is inadequate because the fastener is too short. Furthermore, unsecured panels and improperly installed fasteners can become dropped objects or FOD material. Threaded fasteners in the same panel should have different diameters if their grip lengths are not identical.

Transport: The aircraft has a number of different types of fasteners for access panels, several of which cause problems in the maintenance activities. The cam slot (or airlock) type fasteners are moderately hard to remove. While generally effective, they require close spacing and consequently a large number are needed to secure an individual panel. A more significant problem is the quick-disconnect type fastener used on some stress panels. The fastener used for the Doppler antenna radome panel is designed with both quick-disconnect and threaded-fastening features. This fastener was cited by all five activities visited as very difficult to reinstall after removal because of the threaded-lock device. Reinstallation frequently requires replacement of several of the fasteners. The relatively light structure also was described as a problem area.

Attack fighter: Fiberglass antenna covers (vertical tail and intake leading edge) are installed with rivets in lieu of removable fasteners. Consequently, stripping and refinishing of these covers has to be accomplished without removal of the covers from the aircraft. The aircraft skin adjacent to the antenna covers has to be covered with tape. Although careful procedures are used, the solvents tend to attack the skin finishes. Refinishing usually has to be done two or three times a year.

Attack fighter: The aircraft has weather seals installed with rivets (i.e., speed brake, landing gear doors, pylons, wing fold down area, access doors, engine to fuselage area, etc.). Replacement of weather seals is done frequently (once a year or more) and requires that the rivets be drilled out. Besides consuming time, this process creates a potential for damaging the fastener hole and often results in having to oversize the hole. The engine-to-fuselage seal is frequently removed and has approximately 90 rivets installed. The seal is replaced one or two times a year per aircraft and requires about 12-16 man-hours per replacement. If removable screws are used instead of rivets, considerable time and cost savings would be realized.

Attack fighter: The design of aircraft panels using different size/length fasteners makes installation/removal difficult and time consuming. The types of fasteners used on the aircraft are fairly standard (CAM locks, rivets, and screws); however, the size varies to a great extent. Numerous panels have from three to five different length screws while a few have as many as seven different lengths. The technician is required to sort screws prior to reinstalling skin panels. Many units avoid this necessity by taping the removed screw to the proper panel hole.

Hi-torque screws: The poor removal characteristics of the hi-torque recess has resulted in a high failure rate and excessive man-hours spent removing damaged screws. The high failure rate of the hi-torque recess was reported on three of AFADL's field visits. In addition, the problem has been documented on two other aircraft. Follow-up research as to why the recess has been consistently selected over others showed that it was because of the hi-torque screw's fatigue superiority. However, this criterion is applicable to only a few stress panels, if at all. The problem is compounded because no detailed formal fastener selection criteria define the performance characteristics of the various recesses. Therefore, the problem is easily repeated.

Ground attack: The hi-lock fastener used is semi-permanent and must be removed by drilling or splitting the retaining collar. To remove the nose gear hydraulic actuator, the hydraulic swivel must be removed. This swivel is attached to the aircraft frame by four hi-lock fasteners

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which must be drilled out. Components subject to removal and replacement should be installed with fasteners that facilitate removal.

Bomb dispenser: The bomb dispenser has weather seals installed with rivets around its doors. Replacement of weather seals is done frequently and requires that the rivets be drilled out. Besides being time consuming, this process must be accomplished in the sheet metal shops. There is also a potential for damaging the fastener hole and often results in having to oversize the hole.

Ground attack: The retaining ring on the fastener used extensively on access doors in the aircraft binds on the threads of the fasteners during fastener installation and removal. Damage to the fastener threads or even fastener failure has resulted. When the retaining ring breaks, the fastener is no longer retainable and the broken ring can easily enter into aircraft bays causing FOD. On the aircraft, there are approximately 2,000 fasteners of this type and maintenance records show a high failure rate. Because of numerous inspection and service requirements, the fasteners must be removed and reinstalled often. Each fastener costs $16.00, the retaining ring, $1.69.

Delta wing fighter: A Class C flight mishap occurred on the aircraft where both main and standby attitude indicators were lost for two minutes in a heavy rain shower after a lightning strike. The modification was upgraded to Class IVA safety because of this incident. During accomplishment of the TCTO it was found that standard castellated nuts were installed during production in some areas in lieu of self-locking castellated nuts. A routine TCTO was issued to inspect/replace standard castellated nuts with self-locking castellated nuts at next maintenance opportunity.

A.4.3.14 Fasteners. (___)

A combination of analyses, inspections, and tests shall verify that the requirements of 3.3.14 are met.

VERIFICATION RATIONALE (A.4.3.14)

Verification that each fastener system used in the airframe meets the requirements of 3.3.14 is necessary to assure that the air vehicle will stay together for the duration of its required life.

VERIFICATION GUIDANCE (A.4.3.14)

Drawing call outs for fasteners should identify those characteristics which should be inspected before use in assembly. If the application of the fastener is safety critical or fracture critical or is the major load path between two safety or fracture critical elements or components, each fastener should be verified as meeting the requirements established for the characteristics listed on the drawing. If the verification requires destructive tests, these may be carried out on a lot sampling basis. For routine applications, lot sampling may be used for all verifications.

Screw thread quality assurance provisions contained in MIL-S-8879C (UNJ thread form) and MIL-S-7742D (UN, UNR, and UNM thread forms) are applicable for verification of screw thread. It is strongly advised that fastener selection should be evaluated for the following three categories of fastener application:

Safety of Flight Critical applications

Critical applications (for economic, operational capability, and support)

Other applications

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In accordance with the inspection provisions of MIL-S-8879C and MIL-S-7742D, Safety of Flight Critical and Critical applications should be subjected to thread quality assurance inspection parameters for critical category thread applications called out in the reference specifications. Other applications should be inspected in accordance with the parameters called out for other category thread applications called out in the referenced specifications. In all cases, the use of indicating gaging (instead of functional go/no-go gaging) has been established to be the most reliable measure of thread conformance and fastener performance.

VERIFICATION LESSONS LEARNED (A.4.3.14)

Samples of fasteners in government supply centers taken in 1986 indicated that most were not in compliance with geometry requirements. Further sampling in 1987 indicated that a significant percentage also did not comply with material and mechanical property requirements. These deficiencies could affect the ability of the fastener to be properly preloaded, torqued to set levels, transfer load, withstand repeated loads and resist corrosion. An investigation spearheaded by the RM 2000 office in HQ USAF concluded that manufacturers were not complying with specification verification requirements and that better government verification methods were required. Initially, this will be through more comprehensive receiving inspections. The long term and more effective solution will be to utilize in-process control during fastener manufacture. A second conclusion was that fasteners were often overlooked when examining a design to determine which parts were critical. Fastener design and verification requirements should reflect the application of the fastener.

A.3.3.15 Integral fuel tanks and lines. (___)

Fuel tanks and lines which are integral with or considered a part of the structure of the air vehicle shall meet the following structural integrity requirements: _______________.

REQUIREMENT RATIONALE (A.3.3.15)

Fuel leaks from tanks and lines are obviously hazardous and when the tanks and lines are a part of the airframe, this requirement is needed to preclude safety problems from arising. Fuel leaks, particularly for integral fuel tanks, have been an economic burden and potential safety hazard for most Air Force aircraft.

REQUIREMENT GUIDANCE (A.3.3.15)

Define the structural integrity, including leakage, requirements in the blank. Specific reference to applicable durability and damage tolerance requirements of 3.11 and 3.12 should be made. Regarding leaks, fuel lines should have no inherent leakage in normal service. Integral fuel tanks should have a maximum specified allowance (and repairable) leak rate. Any allowable fuel leak rate should be based upon acceptable maintenance criteria through the full service life of the aircraft.

REQUIREMENT LESSONS LEARNED (A.3.3.15)

One major reason for the significant leak problem is that in the past, structural designers and fuel tank sealant specialists rarely, if ever, coordinated their efforts. Certain designs and fastening systems are prone to leak regardless of the sealing method. Sealants successful in some applications prove inadequate in others. Certification methods and criteria for integral fuel tanks have been non-existent but are now emerging from the R&D community. Sealing method selection may be aided by the information contained in AFWAL-TR-3019.

Swing wing fighter: During the design of the aircraft, it was expected that the existing integral fuel tank sealant would not be acceptable due to aerodynamic thermal heating cycles in excess

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of 250°F. The existing sealant at that time was qualified to 250°F. To meet the increased temperature requirements, a polyester base high temperature sealant was derived for use on faying surfaces and in sealing grooves. The sealant began showing signs of reversion in 1973. The sealant turns to liquid because it is not resistant to high temperature/humidity environments. The sealant was replaced with another sealant on the production line. Navy testing showed that both sealants would revert when exposed to 200°F at 100% humidity. These materials are the reason that the aircraft have to be unsealed/resealed. A polysulfide sealant was incorporated on the last six production aircraft. This sealant has higher temperature performance. MIL-STD approved sealants should be used where possible. Environmental testing must be adequate to detect reversion for non-standard application. In all cases, sample testing and rigid quality control must be ensured during production.

Blind fasteners: Blind fasteners should not be used in aircraft integral fuel tanks. They provide an additional leak path and are not hole filling. They cannot be retorqued to provide faying surface clamp-up. MS 33522 provides guidance for use of blind rivets. Blind rivets should not be used in tanks or in places where a fluid tight joint is required. The following actions have been taken to correct the problem of blind fastener use on fuel tanks. The reseal/unseal work specification has been revised to prohibit use of blind fasteners. The fighter SPO has taken action to eliminate over 90% of the blind fasteners in the integral fuel tanks area on a production aircraft. An AFSC Design Handbook is being revised to state clearly that blind fasteners may not be used in the design of integral fuel tanks.

Ground attack: Integral fuel tank leakage on the aircraft is a major problem and is one of the major contributors in ground aborts. Observations of the sealing process revealed numerous discrepancies of workmanship and manufacturing techniques. Because of the critical nature of the fuel tank sealing process, quality control requirements should be stressed in tank sealing and repair operations. Sealing operations should be done in an area where foreign object contamination is at a minimum.

Heavy air/ground fighter: Non-alignment of the integral fuel tank sealant groove has resulted in an excessive number of unnecessary maintenance actions to repair fuel leaks. The aircraft incorporate a wing integral fuel tank sealant groove containing a non-curing fluorosilicone sealant as a primary means of fuel containment in the tank faying surfaces. The sealant groove is contained in the wing spar, rib, and skin structural components. Mismatch of the sealant groove as it traverses two or more structural components exists. This mismatch causes a reduction or blockage of the sealant channel grooves and prevents successful injection of the sealant.

Air superiority fighter: The full scale development aircraft has numerous fuel leaks due to (1) poor quality in hole preparation, rivet installation, and sealant application, (2) lack of fillet seals in many areas due to no access for application, and (3) the choice of blind rivets which were unable to properly fill the poorly prepared holes. These problems were resolved by the addition of 16 access doors to the fuselage integral tanks; the replacement of blind rivets by bucked rivets, threaded bolts, structural screws and hi-lok fasteners; the use of pilot hole drilling and drill blocks to improve hole quality; and the use of rotating fixtures to improve sealant application and pressure checks. In addition, permanently attached nuts should be utilized in inaccessible areas to allow torque of leaking bolts or bolt replacement.

Light air/ground fighter: A major accident resulted in the action of the Fuel Manifold System being redesigned to minimize the probability of fuel leaks.

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A.4.3.15 Integral fuel tanks and lines. (___)

Analyses and tests shall verify that the requirements of 3.3.15 are met.

VERIFICATION RATIONALE (A.4.3.15)

Verification of the sealing integrity of those components of the airframe holding or carrying fuel needs to be accomplished to show that the requirements of 3.3.15 have been met and that the airframe will not contribute to hazardous and unsafe fuel leakage conditions.

VERIFICATION GUIDANCE (A.4.3.15)

Total environment durability tests of integral fuel tank components should be tested to verify both structural integrity and fuel containment for all tank and sealing concepts. Refer to AFWAL-TR-80-3100.

VERIFICATION LESSONS LEARNED (A.4.3.15)

A.3.3.16 Nuclear weapons retention. (___)

The retention of nuclear weapons requirements are __________. The support and suspension system shall meet the damage tolerance requirements for fail-safe multiple load path structure of 3.12.2.2.

REQUIREMENT RATIONALE (A.3.3.16)

The inadvertent loss of a nuclear weapon is most undesirable. The requirements for retention and release of nuclear weapons are closely controlled by Air Force regulations.

REQUIREMENT GUIDANCE (A.3.3.16)

Reference and include applicable requirements of AFR 122-10 and related regulations regarding the retention and release of nuclear weapons as they apply to the structural integrity requirements of the airframe.

REQUIREMENT LESSONS LEARNED (A.3.3.16)

A.4.3.16 Nuclear weapons retention. (___)

Analyses and tests shall verify that the requirements of 3.3.16 are met.

VERIFICATION RATIONALE (A.4.3.16)

Verification of the structural integrity of the airframe to retain nuclear weapons under all conditions except those resulting in loss of the air vehicle is needed to assure that the requirements of 3.3.16 are met and that every effort was made to not create a nuclear hazardous condition inadvertently.

VERIFICATION GUIDANCE (A.4.3.16)

VERIFICATION LESSONS LEARNED (A.4.3.16)

A.3.3.17 Rapid decompression. (___)

The safety of flight structure shall possess in-flight evident residual strength (3.12.2) to withstand rapid decompressions from which recovery is expected. If the pressurized structure has several compartments separated by partitions, bulkheads, floors or combinations thereof, the safety of flight portions of the structure shall withstand the pressure differential caused by the sudden release of pressure in any compartment during any approved operating or maintenance usage of the air vehicle. Venting and other means of controlling the differential

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pressure between compartments is permitted. The structure, including nonstructural compartment bulkheads, wall and ceiling panels, doors, etc., shall not cause injury to properly restrained personnel within the compartments. The probable size, shape, and location of the opening that causes sudden decompression shall be rationally established. Such failures shall not degrade, damage, or cause to fail any other components of the flight control, fuel, hydraulic, or electrical systems, such that safe, continued, and controlled flight is in question. Sources of openings shall include:

a. All openings that result from system failures defined in 3.2.22.

b. Subcritical cracks or arrested critical cracks originating from fatigue or induced flaws.

c. The following occurrences and any others considering the operational experience of similar air vehicles performing similar missions:

   (1) Bird strikes.

   (2) The largest portions of any engine or propeller following disintegration.

   (3) Failure of other subsystems.

d. Other.

REQUIREMENT RATIONALE (A.3.3.17)

Pressurized compartments of aircraft are subject to penetrations in flight or loss of windows, windshields or doors which will result in rapid decompression of the affected compartment. This rapid decompression results in abnormally increased pressure differentials in partitions, bulkheads, or floors which separate pressurized compartments. The requirement is established for the purpose of:

a. Rationally identifying possible sources of penetration or failures which would result in rapid decompression.

b. Determining the probable size, shape and location of such openings for use in analysis to determine the magnitude of the resulting pressure differentials which must be withstood without further failure of safety of flight structure, critical subsystems, or injury to personnel occupying such compartments.

REQUIREMENT GUIDANCE (A.3.3.17)

This requirement is applicable if the aircraft is pressurized. The objective of the requirement is to rationally determine potential causes of penetration or failure of pressurized compartments using past service experience of similar aircraft as the data base. For example, a survey of pressure shell penetrations and failures of jet transport aircraft showed that the maximum hole size expected to be exceeded once in 109 flight hours is 4.6 ft^2 for narrow body aircraft and 12 ft^2 for wide body aircraft. It should be noted that this survey was based on service experience of two narrow body and three wide body commercial aircraft up to 1976. With the advent of new narrow body aircraft using two larger engines, this type of survey is no longer valid and the maximum hole size must be determined for the specific aircraft configuration under consideration. Openings caused by internal explosions and mid-air collisions are eliminated from consideration since the potential hole size can very likely exceed that which the intact structure can tolerate when subjected to normal flight loads. In establishing the design criteria for pressurized compartments, consideration must be given to the loss of windows, outward opening escape hatches, windshields and penetrations by the largest portions of a disintegrated engine, propeller, or other rotating machinery such as auxiliary power units. All possible paths of penetration should be examined to establish the size, shape, and location of the openings for

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analysis of the flow of internal pressurized air from all other pressurized compartments, taking into consideration venting inherent to the structural configuration, to determine the maximum pressure differential to be expected. This pressure differential is taken as an ultimate load to perform stress analysis of the structure (bulkhead, floor, partition, etc.). Trade-off studies are an appropriate means of optimizing venting area and structural strength for any given failure mode.

REQUIREMENT LESSONS LEARNED (A.3.3.17)

There have been numerous incidents of rapid decompression of both civil and military pressurized aircraft caused by uncontained engine failures, propeller failures, bird strikes, structural fatigue failures, loss of windows, loss of doors, failure of subsystems, battle damage, bomb blasts, and in-flight collisions. While the damage to primary structure which may be caused by bomb blasts and in-flight collisions may not in itself be survivable, the damage caused by other sources is generally limited such that if no induced structural damage occurs and if critical flight and propulsion control systems are not excessively damaged, continued flight and safe landing may be possible. The background for this requirement stems from a series of accidents which occurred in the early 70s involving loss of doors on two commercial and one military aircraft. Two of the three aircraft crashed with major loss of life. Both crashes were ultimately caused by loss of critical flight controls due to induced damage and not to the failure of the door itself. Studies conducted by the Aerospace Industries Association, the Federal Aviation Administration, and the ASC Structures Division concluded that it is impractical to incorporate features in the design of aircraft which would tolerate the loss of any size door. It was, therefore, concluded that features must be incorporated in the design of doors of all sizes to assure that failure and loss of a door is extremely improbable. The studies then focused on other probable causes of rapid decompression which could be expected to be survivable.

A.4.3.17 Rapid decompression. (___)

Analyses and tests shall verify that the airframe structure complies with the requirements of 3.3.17.

VERIFICATION RATIONALE (A.4.3.17)

Verification of the adequacy of the airframe to withstand rapid decompression is needed to ensure that adequate structural integrity exists in the airframe so that the safety of the crew and the recovery of the air vehicle is optimized.

VERIFICATION GUIDANCE (A.4.3.17)

VERIFICATION LESSONS LEARNED (A.4.3.17)

A.3.3.18 Design provisions for ship-based suitability. (____).

A.3.3.18.1 Wing design provisions for ship-based suitability (____).

A.3.3.18.1.1 Wing folding or sweeping (ship-based aircraft). (____)

Deck stowage space shall be minimized by providing means for folding the wings, or alternatively, sweeping them in conjunction with a variable sweep design.

REQUIREMENT RATIONALE (A.3.3.18.1.1)

This paragraph provides guidelines for minimizing aircraft dimensions to permit shipboard storage and maintenance.

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REQUIREMENT GUIDANCE (A.3.3.18.1.1)

Wing folding and spreading operations should be accomplished either manually or by power. Wings folded by power shall permit decoupling of wing locking mechanism and should have manual or other alternate provision for folding the wings. It shall be possible to refuel wing fuel tanks (including outer panel tanks), load ammunition, and service guns and other equipment with the wing folded or swept and spread. External stores installations on folding or sweeping part of the wing shall meet the strength requirements of paragraph 3.4.1.1 of SD-24 Vol I. (For securing of folding wings see paragraph 3.22.6 of SD-24 Vol I.). It should be possible to do full power engine runups with the wings in the folded or swept position. Required maintenance should be possible with the wings in the folded or swept and over-swept positions.

It should be possible to fold or sweep or spread the wings in not more than 20 seconds under the following conditions:

a. In winds up to 60 knots from any direction between plus or minus 45 degrees from ahead.

b. With most critical installation of any items specified for installation on the outer wing panels.

c. Engine revolutions per minute to be that which is satisfactory for use when standing or taxiing on a ship deck.

d. Unless otherwise specified, folding or sweeping or spreading should be accomplished with all control surfaces on either the outer or inner panels in any position. Unless otherwise specified, interlocks shall be provided to prevent wing folding until flap retraction, or any other necessary operation is completed.

e. Strength for wing folding or sweeping shall be as required by paragraph 3.4.1.1 of SD-24.

f. The wing-fold actuator attachment should not be an integral part of the wing-fold rib, but should be a replaceable fitting which shall be designed so that, in the event of a failure due to overload or fatigue, failure of the fitting will occur in lieu of failure of the wing-fold rib.

The movable wing hinge-pins shall be locked in the spread position by positive mechanical locks. Neither the control handle nor the mechanical locking pins shall move to the locked position with full manual effort applied unless the outer wing panels are in the fully spread position and the movable hinge-pins are in the locked position. When the movable hinge-pins are controlled from the cockpit, the mechanical locks shall be operated by a separate cockpit control. Provision shall be made to mechanically prevent the movable hinge-pins from moving to the locked position until the wings are fully spread. A mechanically operated warning flag, conspicuously marked and readily visible to both the pilot and the ground crew, shall be provided on each wing to indicate when the mechanical hinge-pin locks are not engaged. Unless otherwise specified, the movement of the warning flag shall be made through the mechanical lock-pins in such a manner as to preclude the possibility of the flags being moved unless all mechanical lock-pins are in the locked position. No single mechanical failure in the mechanical lock system shall result in the warning flag moving to the wings-safe-for-flight position. Wing hinge-pins, locks, and mating parts shall be of corrosion resistant materials or have permanent protection against corrosion applied. Action of the hinge-pins and locks, if dependent upon free application of grease, shall not be affected by accumulation of sand and grit.

Clearance shall be provided in the folded position and during the folding operation to prevent damage to the wing, equipment attached thereto, and to other parts of the aircraft.

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Unsymmetrical shock-absorber deflections, resulting from one wing being folded before the other, shall be combined with a flat tire on the low side in determining critical clearances. With the wings folded or swept, it shall be possible to retract and extend the landing gear in order to check its operation. Except when the gear retracts into the folding portion of the wings, a complete retraction and extension cycle, including up-lock operation, should be possible.

Provisions should be made for locking, folding, or sweeping wings or other surfaces of ship-based aircraft in the folded position. Locks will be an integral part of and shall operate in the sequence with the folding mechanism. Locks shall be positive and shall not depend on hydraulic pressure or other power sources to remain engaged. Locks shall be capable of withstanding forces created by 100 knot winds from any horizontal direction. Removable wing or other surfaces securing devices (for example, jury struts) may be used in lieu of integral locks only when specifically authorized by NAVAIR. These devices shall be such that one man can secure the wings in winds up to 60 knots from any direction between plus or minus 45 degrees from ahead. The locking arrangement shall be positive and made of corrosion resistant material.

Aircraft fitted with variable sweep wings will meet the following additional requirements:

a. The wings will be mechanically interconnected to prevent asymmetric motion.

b. The wing-pivot journals and bearings will be designed redundantly. This principle may be achieved by use of sleeved journals and multiple rubbing surfaces.

c. Positive locks will be provided for variable sweep wings to hold the wings in the forward and after positions specified in detail specification.

d. A variable sweep drive system with manual or mechanical control shall include feel detents for wing positioning at discrete sweep angles as specified in the detail specification.

e. A wing sweep system cockpit indicator shall be included to provide the pilot with the commanded, actual, and structurally limiting sweep angles.

f. Provisions shall be made to prevent ice and other foreign matter from causing wings to be become inoperable.

g. Unless otherwise specified, wing sweep mechanism and components should be interchangeable between left and right side installations.

REQUIREMENT LESSONS LEARNED (A.3.3.18.1)

A.3.3.18.2 Empennage design for ship-based suitability. (____)

The tips for vertical fin, horizontal stabilizer, or other empennage surfaces must be detachable to facilitate repair. If empennage surfaces are folding, they shall be designed such that necessary maintenance can be performed with the surfaces in the folded position.

REQUIREMENT RATIONALE (A.3.3.18.2)

Damage to empennage aerodynamic surface tips is relatively common due to impact damage from ground support equipment and adjacent aircraft. Replaceable tips minimize aircraft down time for repair. Maintenance must be able to be performed with folded surfaces to avoid respotting aircraft, with the attendant significant increase of maintenance time and/or reduction of number of aircraft that can be carried shipboard.

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REQUIREMENT GUIDANCE (A.3.3.18.2)

Empennage control surface tips should be inexpensive and easily removed with organizational level tooling. In addition, the tip attach structure needs to be suitably robust to minimize damage from repeated fastener installations and removals.

REQUIREMENT LESSONS LEARNED (A.3.3.18.2)

Empennage tip damage is one of the most common types of airframe structural damage on Naval aircraft. In addition to damage to the surface edge itself, F/A-18 aircraft have sustained delaminations in the composite "C" channel to which the edges are attached. These delaminations occurred because the channel was not designed to withstand out of plane bending resulting from fastener removal.

A.3.3.18.3 Cockpit/cabin design for ship-based suitability. (____)

For aircraft designed for catapulting, means shall be provided for crew members to brace themselves during catapult operations. Drains shall be provided at low points of cockpits.

REQUIREMENT RATIONALE (A.3.3.18.3)

Catapult operations subject crew members to longitudinal (N_X) accelerations in excess of normal flight operations. In addition, shipboard operations subject the cockpit to salt spray which will accumulate in the cockpit and cause significant corrosion damage, if drain provisions are not provided.

REQUIREMENT GUIDANCE (A.3.3.18.3)

Aircraft cockpit and flight decks shall have means of restraining crew arms and legs during catapult. In addition, cockpits shall be designed to preclude trapping salt water. Low points shall be drained to the outside.

REQUIREMENT LESSONS LEARNED (A.3.3.18.3)

Cockpit corrosion is a major rework item on carrier born aircraft. Corrosion is typically concentrated in water entrapment areas.

A.3.3.18.4 Equipment compartment ship-based suitability requirements. (____)

Equipment compartments (bomb bays, electronic bays, etc) shall be accessible without the requirement for support equipment such as work stands or ladders.

REQUIREMENT RATIONALE (A.3.3.18.4)

The extremely confined environment of shipboard operations necessitates minimization of ground support equipment on the hangar and flight decks.

REQUIREMENT GUIDANCE (A.3.3.18.4)

Requirement is self explanatory.

REQUIREMENT LESSONS LEARNED (A.3.3.18.4)

Shipboard operating experience indicates that ground support equipment accounts for much of the maintenance induced damage incurred by aircraft. In addition, maintenance action is greatly slowed by the need to transport ground support equipment from storage areas to individual aircraft. Movement of this equipment between the multiple deck levels onboard ship is difficult.

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A.3.3.18.5 Landing gear carrier suitability requirements. (____)

For aircraft with nose wheel type gear arrangements, the landing gear geometry shall be in accordance with Navy Drawing 607770. Landing gears of ship-based aircraft shall include provisions to prevent damage due to repeated sudden extension of the landing gear as the wheels pass over the deck edge subsequent to catapulting, bolter, or touch and go. Also the landing gear shall not contain features such as sharp projections or edges that could cause failure of the arrestment barricade. Landing gear wells shall be designed to allow a 3.5 percent increase in tire size due to over inflation. To preclude striking catapult shuttles and PLAT camera covers, the centers of nose wheel axles shall clear the deck by at least 6.5 in. when the tires are flat. Tires shall be selected such that neither the nose or main landing gear tires are not fully deflected during catapult. If the nose landing gear has a stored-energy type strut, the energy stored in the shock absorber shall be sufficient to provide rotation of the aircraft to flight attitude at the end of the deck run in the event that one or both nose gear tires have failed during the catapult.

The wheel brake hydraulic system shall be capable of providing adequate braking for deck handling without engine operation or external power packages, and be able to perform at least 10 applications of the normal brake before a hand pump or other means must be utilized to repressurize the brake system. A pressure indicator shall be provided in the pilot's cockpit. A parking brake shall be provided as well. A "park-on" cockpit warning system or an automatic park brake release system shall be provided to preclude "brakes-on" during catapulting.

REQUIREMENT RATIONALE (A.3.3.18.5)

The requirement of 3.3.18.5, have all proven necessary to permit safe ship-board aircraft operation. Landing gear geometry requirements are necessary to prevent aircraft roll over during ship rolls or tip back during arrested landing pull back. Barricade arrestment is necessary during failure of aircraft arresting hook or landing gear.

REQUIREMENT GUIDANCE (A.3.3.18.5)

The aircraft design shall meet all the criteria of 3.3.18.5

REQUIREMENT LESSONS LEARNED (A.3.3.18.5)

A.4.3.18 Design provisions for ship-based suitability. (____).

A.4.3.18.1. Wing design provisions for ship-based suitability. (____).

The contractor shall perform design checks to ensure that the requirements of 3.3.18.1 are met early enough in the design process to preclude development cost and schedule penalty.

VERIFICATION RATIONALE (A.4.3.18.1)

At best ensuring that the design meets the requirements of 3.3.18.1 precludes time consuming and costly design changes resulting from shortcomings identified during carrier suitability testing. Violating some of the above criteria may result in the aircraft being deemed unusable in the carrier environment.

VERIFICATION GUIDANCE (A.4.3.18.1)

A carrier review team or "graybeard" should review the overall design for compliance with the above requirements.

REQUIREMENT LESSONS LEARNED (A.4.3.18.1)

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A.4.3.18.2 Empennage design for ship-based suitability. (____)

During engineering development, the contractor shall ensure that the requirements of 3.3.18.2 are met by the design.

VERIFICATION RATIONALE (A.4.3.18.2)

Redesign to incorporate the required features is very time consuming and costly.

VERIFICATION GUIDANCE (A.4.3.18.2)

Design teams should be aware of specification induced design requirements.

VERIFICATION LESSONS LEARNED (A.4.3.18.2)

A.4.3.18.3 Cockpit/cabin design for ship-based suitability. (____)

During engineering development, the contractor shall ensure that the requirements of 3.3.19.3 are met by the design.

VERIFICATION RATIONALE (A.4.3.18.3)

VERIFICATION GUIDANCE (A.4.3.18.3)

Testing shall be in accordance with MIL-D-8708.

VERIFICATION LESSONS LEARNED (A.4.3.18.3)

A.4.3.18.4 Equipment compartment ship-based suitability requirements. (____)

Contractor should perform and document human factors studies to ensure that all equipment bays can be reached without need for ground support equipment.

VERIFICATION RATIONALE (A.4.3.18.4)

VERIFICATION GUIDANCE (A.4.3.18.4)

Testing shall be in accordance with MIL-D-8708.

VERIFICATION LESSONS LEARNED (A.4.3.18.4)

A.4.3.18.5 Landing gear ship-based suitability requirements. (____)

Barricade requirements shall be demonstrated by test. Otherwise requirements shall be verified through the design review process early in the engineering development process.

VERIFICATION RATIONALE (A.4.3.18.5)

Retrofit of the above requirements would be very costly and schedule disruptive. The design requirements in 3.3.18.5 must be addressed during early aircraft configuration studies.

VERIFICATION GUIDANCE (A.4.3.18.5)

Testing shall be in accordance with MIL-D-8708.

VERIFICATION LESSONS LEARNED (A.4.3.18.5)

A.3.3.19 Repeatable release holdback bar. (_____).

The holdback bar shall restrain the aircraft against aircraft engine thrust, catapult tensioning force, and ship motion. The holdback bar shall be of the repeatable release type and shall be designed in accordance with MIL-B-85110. The configuration of the lower portion (deck end) of

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the holdback bar shall conform to the requirements of NAEC Drawing 607770. The design load for the aircraft holdback bar is __________.

REQUIREMENT RATIONALE (A.3.3.19)

This requirement defines the holdback load level design for shipboard operations.

REQUIREMENT GUIDANCE (A.3.3.19)

For the release element, the minimum release load R (in pounds) for the repeatable release device is:

R = 1.35(Thrust + 5500 + 0.2 Max Catapult Weight)/Cos (angle between holdback axis and deck at release)

where the allowable tolerance is +5% and -0% of R.

The design release load for the airframe design H (in pounds) at the nose gear holdback fitting is:

H = 0.06R + 1.65(Thrust + 5500 + 0.2 Max Catapult Weight)/Cos (angle between holdback axis and deck at release)

where thrust (lbs.) is the maximum thrust with thrust augmentation devices operating, if the aircraft is so equipped, including surge effects from ignition at sea level on a 20° day (lbs). The initial horizontal component of the tensioning force applied by the catapult shuttle is 5500 pounds and is reacted by the holdback assembly.

For "Buffing", the holdback bar engages the slider of the catapult deck hardware at all critical angles resulting from the spotting requirements of MIL-L-22589. During the buffer stroke, a tension load equal to the load 'H' shall be applied to the aircraft holdback fitting.

For release, the aircraft shall be in all attitudes resulting from the release operation. The deflection of tires and shock struts shall correspond to the forces acting. The load in the launch bar shall be that required for equilibrium. The side loads shall be those resulting form the maximum possible misalignment of the launch system in combination with spotting conditions of MIL-L-22589.

REQUIREMENT LESSONS LEARNED (A.3.3.19)

The design load level of the holdback is crucial to carrier launch operations. Too low of a release load level and during engine run-up with heavy sea state conditions, the aircraft will release prematurely; too high of a level and at light weight, high wind over deck values with low CSV setting, release may not occur, or significant head-bob will be experienced by the pilot causing disorientation during launch.

A.4.3.19 Repeatable release holdback bar (____)

Analyses and tests shall verify that the repeatable release holdback bar has the capability to perform as required by 3.3.19.

VERIFICATION RATIONALE (A.4.3.19)

Because of safety of flight, this component of the aircraft system will be both laboratory ground tested and verified by numerous carrier suitability compliance tests. In addition, a statistical test will be performed on each release bar to verify its minimum release compliance level.

VERIFICATION GUIDANCE (A.4.3.19)

Carrier suitability tests shall be performed in accordance with MIL-D-8708B.

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VERIFICATION LESSONS LEARNED (A.4.3.19)

A.3.3.20 Other design and construction parameters. (____)

___________.

REQUIREMENT RATIONALE (A.3.3.20)

This requirement is needed to provide flexibility and coverage of additional design and construction requirements that may arise or exist at the time the Type I specification is being prepared.

REQUIREMENT GUIDANCE (A.3.3.20)

Identify and define other design and construction parameter requirements as applicable. Such requirements will generally stem from specific lessons learned for particular types of structural components or assemblies and are applicable only to selected air vehicles. Review and include as applicable the Standardization Agreements 3212ASP on diameters for gravity filling orifices and 3681PHE on criteria for pressure fueling of aircraft.

REQUIREMENT LESSONS LEARNED (A.3.3.20)

Accessibility

Double access panels. An offset design of double access panels on reentry vehicles, combined with limited space between the panels has resulted in excessive man-hours to remove/reinstall the attaching fasteners of the inner panel. Several man-hours are expended to remove/reinstall the inner door to the arm and disarm equipment just to perform simple safing procedures. The limited working space is the primary reason for the difficulties the maintenance technician has when removing/reinstalling the fasteners of the inner door. However, the selection of an attaching fastener with the hi-torque access design compounded the problem. In order to remove/reinstall a hi-torque fastener, the hi-torque adapter tool must be fully inserted into the access or it will disengage, rout-out the access, and destroy the fastener.

Swing wing fighter/ground attack: The damage of a single nutplate or gang channel nut element that is used on access panels or mating assemblies, all too often results in excessive disassembly just to gain access for replacement. On one aircraft to repair a missing or damaged nutplate on any of four access panels, an adjoining permanently installed skin has to be removed and replaced. Even though it takes just a few minutes to replace the nutplate, several hours are required to remove and replace the skin. On the engine used on the other aircraft, in order to replace one of the 84 gang channel nut elements that is used to mate the turbine compressor to the combustion case, the complete turbine section and engine mount ring must be removed. With the mount ring removed the engine support stand cannot be used to support the engine. Therefore, the engine has to be rotated to the vertical position for removal of the combustion case. The complete operation usually requires two days.

Transport: The procedure for removing and replacing one windshield panel entails removing five instruments to gain access to the individual windshield nuts and bolts. The problem has been reviewed by the system manager. No fix action is currently contemplated, because changing windshield panels is a low maintenance man-hour item. Accessibility to the windshield should be a designed-in feature of future instrument panels. A large transport instrument panel, for example, has a center section that disconnects quickly and slides out easily for access to the rear of the panel.

Transport: Due to the design of some moveable antennas on avionics system, such as APN-147 Doppler and APN-59 radar, it is frequently necessary to perform visual inspection. Without

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a visual inspection capability, it becomes necessary to remove the antenna cover or radome, which causes unnecessary wear on the hardware and excessive man-hours. For those antenna which require visual inspection, design a means to gain visual access without having to remove antenna covers, such as the window used to insure that the C-130 landing gear is locked.

Transport/swing wing fighter: Several problems associated with the wiring locations and electrical cables were identified by maintenance activities. On the transport, wiring located under the cargo compartment flooring requires that large flooring sections be removed to gain access. This may also require removal of the cargo rails to get to the flooring sections for removal. Since wiring runs under many sections of flooring, a short or opening in a wire may require the removal of several sections to gain access for troubleshooting and repair. The units also indicated that wire bundle cables with electrical connectors should have sufficient slack to permit easy connection to the component. On the swing wing fighter this problem is prevalent on the TFR rack located in the nose section and the horizontal situation indicator, airspeed mach indicator, and the altitude vertical velocity indicator, which are located in the cockpit. Because the cables are short and accessibility is limited, a person has to reach around behind the units and make a blind connection which is particularly frustrating. Another problem area with wiring is that some wire bundles are, of necessity, routed through structural members of the aircraft or through other access holes. The connectors attached to the bundle end, in some instances, are larger than the access clearance for the wiring. If the cable must be removed for any reason, such as to gain sufficient slack to repair a broken wire in the bundle, this means the connector must be removed so the wiring can be withdrawn. Removal and replacement of the electrical connectors is a time consuming and tedious process. In addition, every time the wires are cut and the connector replaced, the cable is shortened.

Swing wing fighter bomber: A panel is installed with screws and nuts (no nut plates) and is difficult to remove. This panel requires frequent removal for hydraulic access, fuel leaks, and throttle cable changes. The panel is installed with screws and nuts. An adjacent panel must be removed to remove and install the other panel. The panel is also removed for 400-hour phase inspection. Many maintenance man-hours are expended in removing/installing the panel.

Swing wing fighter bomber: The aircraft uses hi-torque screws to fasten the hydraulic system access door. Removal of the fasteners for the purpose of servicing or testing the hydraulic system is time consuming and difficult. In many cases, a machinist is required to remove failed fasteners. The panel is hinged and quick disconnect hydraulic couplings are used. Only the fastener is not designed for ease of maintenance. This panel is on the right side of the fuselage in the main wheel well area. Access panels (except stress panels) or those located where loose parts can be drawn into an engine should be designed with quick release fasteners to provide ease of maintenance and aid in reducing aircraft downtime.

Swing wing fighter bomber: The overspeed warning system on the engine has had many false alarms and failures. Major cause for the failures is the wiring. Secondary cause is sheared tach generator shaft. The tach generator used to monitor the revolutions per minute (RPM) of the N1 compressor is mounted on the nose cone of the engine. The wiring is run through the guide vane and must be cut if the tach is replaced or the guide vane removed. The wires are spliced together when the tach is hooked up. The spliced wires create problems by shorting, opening, and poor continuity. This problem is aggravated by the fact that the inlet guide vane is presently experiencing a high failure rate and must be removed for repair. This causes repeated cuts and splices of the tach generator wiring. Installation and removal of components/parts should be able to be done without cutting wires.

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Swing wing fighter bomber: The alternate landing gear extension system is serviced through a charging valve located in the MLG wheel well. This valve (which is common to other emergency pneumatically activated systems) is normally easy to reach; however, when the aircraft is fully loaded, the valve becomes inaccessible. The airframe sits so low that the right MLG strut will not allow enough clearance to hook up the service hose. If any of the emergency systems linked to the common valve requires servicing, the only way to gain access is to pump up the struts to full extension and then readjust the struts after servicing. If this valve were located a few inches forward of its present location, the interference problem would not exist.

Swing wing fighter bomber: The forward equipment cooling duct has become brittle with age, and is experiencing a high failure rate because of cracks and breakage. Repairs of the duct on site are usually unsuccessful. Replacement is difficult because of inaccessibility. Replacement of the ducting requires removal of all avionics equipment and equipment racks on the right hand side and some on the left side. Replacement of the duct requires 36 to 48 man-hours. Vibration and temperature fluctuations increase the failure rate of the brittle cooling duct. The system manager has an agreement with depot maintenance to inspect cooling ducts whenever the forward equipment bay is opened for work during programmed depot maintenance. If the defect in a cooling duct is obvious, then repair is initiated. Aging has caused the polyurethane-type material in the forward equipment cooling ducts, located in a highly inaccessible area, to become brittle and crack. Many man-hours are required for replacement.

Transport: Rubber flap type drain valves are installed in the lower fuselage to allow draining of moisture accumulated from natural condensation, leaks, and spillage. This draining is an important part of the corrosion prevention program. When these drains become blocked with debris, standing moisture results. Debris enters the interior of the aircraft moisture drain area through the valve and the floor panels in the cargo compartment. Gaining access to clear or replace these rubber flap drains is very time-consuming. The technical order specifies normal cleaning or replacement of drain valves during programmed depot maintenance. However, failure to gain access and clean or replace drain valves at more frequent intervals results in major corrosion repair/replacement.

Attack fighter: The design of the avionics and other component bays on the aircraft is a very desirable feature. Most of the items which require frequent maintenance are located in bays that can be easily reached by a mechanic standing on the ground. This feature enhances safety, makes for ease of work, and reduces the amount of support equipment required for this weapons system.

Transport: The throttle control incorporates a system of mechanical cables from the throttle quadrant to the engines. The cables are routed through a series of three 90-degree turns. The small diameter pulleys used at these turn points apparently contribute to fraying and other cable failure problems that are being experienced. Although the system manager is considering a modification to increase the size of the throttle cable pulleys, the more serious problem involves inaccessibility, because the cables are routed under the flight deck and through other hard to get at places, visual inspection of some critical segments of the cables is impossible. Moreover, braided cable is used on the throttle control. This type of cable is difficult to inspect adequately because points of weakness may be hidden from view. These weaknesses which have been known to cause throttle control failures have been corrected by new cables and larger pulleys. Another problem involves the use of cables for remote actuation of switches and valves which have critical adjustments in position, such as the hydraulic ground test selector valve and the flap position indicator. Proper adjustment and tensioning of these cables is difficult and time-consuming.

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Transport: The bolts which mount the engine to the aircraft are very hard to torque since the bolts are located between two of the main engine supporting arms. An extension of approximately 6 inches or more is required to reach and torque the bolts. Since high torque is required with an extension, sometimes the socket slips off the bolt resulting in damage to the engine or individual doing the work. Structural or supporting bolts, which require high torque need to be accessible for torquing without the aid of extensions.

Air superiority fighter: Removal of the cockpit canopy is necessary when the ejection seat is removed from the aircraft for inspection and modification of ejection components (lines, initiators, chutes, etc.) or for replacement of avionics components behind the seat. The task of removing the canopy is time-consuming and requires special support equipment slings and special handling precautions to prevent scratching or abrasion of the optical surface. The canopy removal and reinstallation requires eight man-hours and three clock hours. A delta wing fighter does not require removal of the canopy in order to remove the seat.

Swing wing fighter: The aircraft has 17 access panels that use form-in-place seals. To replace the form-in-place seal, maintenance personnel must first remove the old sealant by solvents and hand scraping. The surface where the seal is to be applied is cleaned and primed and the primer is allowed to cure. The fastener holes are then covered with plastic or washers and the sealant is applied. The access cover or door is positioned over the sealant with fasteners at least every fourth hole and the sealant is left to cure. After curing, the cover/door is removed, cleaned and reinstalled using all the specified fasteners. The scope of the task can be appreciated, considering that two access covers have 174 fasteners each. A review of data for a six month period indicates that 1363 man-hours were expended on these two covers as opposed to only 662 man-hours for two other access covers which do not have form-in-place seals. Easily replaceable, expendable seals cut from sheet stock or seals fabricated from molded rubber as composition material are more desirable.

Ground attack: Servicing of the LOX system on the aircraft is required before each flight. The LOX converter is located behind an access panel which, due to the proximity of the nose landing gear hinge points, was designed as a stress panel. This panel, with 21 fasteners, must be opened and resecured for servicing of the LOX system. This procedure requires over 20 minutes. Air National Guard units have modified this access panel with a small, quick-open, servicing door. Their servicing time is now three minutes. The average airplane flies three sorties per day; which means a savings of almost one hour servicing time per day per airplane flown.

Bomber: The track antenna azimuth drive motor cable connector was placed behind the right side brace on the gun turret, beneath the track transmitter installation. Removal of the search antenna requires disconnecting this and other connectors. To disconnect the connector the maintenance technician must either remove the track transmitter to gain access or reach up from beneath with a long screwdriver, using the tip to loosen the connector. When wiring repairs are required on the connector (which is frequent because of the age of the equipment, compounded by high vibration which occurs during gun firing), the track transmitter must be removed. Removal and replacement takes several hours to accomplish because the upper right machine gun must also be partly removed to get the track transmitter out. Upon reinstallation the connector must be safety wired. Had the connector been located directly behind the antenna, as the elevation drive motor connector was, access would not have been a problem.

Subsonic trainer: Engine removal and replacement is one of the most difficult and time-consuming tasks on the aircraft. The difficulty results primarily because the aircraft is low to the ground and designed with embedded engines that can only be removed from the underside of

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the nacelle. In order to remove the engine, the aircraft has to be jacked. This necessitates towing the aircraft to a hangar to avoid the possibility of wind blowing it off the jacks. The engine has to be removed frequently for other maintenance actions. The tailpipe, which is frequently removed for repair of cracks, cannot be removed unless the engine is removed first. The same is true of the fuel control, which is highly susceptible to leaks and requires frequent adjustment.

Subsonic trainer: Seat removal is not as complicated as for many other aircraft, but it is still a process that requires a significant amount of time. When an ejection seat is removed, it is usually to facilitate maintenance on other items rather than to repair the seat itself. Some of the principal actions requiring seat removal include adjustment of flight control sticks, throttle controls, and linkage; rigging of elevator control cable and canopy actuator declutch cable; and adjustment of flap detent. Although seat removal takes only 1.5 hours, it is a frequently required action and represents a significant cost over the life of the system. Cables and other items requiring that the seats be taken out cannot always be rerouted, but some means of adjustment with the seats installed is desirable.

Subsonic trainer: The design of the passing and taxi lights has caused a serious accessibility problem. A light check is required just before takeoff, and if either the taxi or passing bulb fails to function, replacement takes over 30 minutes and delays the flight. Since the aircraft sits close to the ground, the nose strut is not sufficiently exposed for the two lights to be positioned on it (as they are in many other aircraft). Instead, the passing and taxi lights are located behind the nose cap and are protected by clear windows. These windows are attached by screws and nuts (rather than by screws and nutplates) and as a result are extremely difficult to remove and install. The only practical way to get at the lights is by removal of the nose cap (fastened to the airframe by 24 screws) and the pitot tube; although even with this means of access, the job requires several maintenance personnel and over half an hour.

Subsonic trainer: The nose gear steering valve, located atop the strut, often must be removed because it is prone to hydraulic fluid leaks. When the valve malfunctions or needs adjustment, the entire nose gear assembly must be replaced. This requirement ties up a number of maintenance personnel for several hours.

Subsonic trainer: The four brake control units on the aircraft are located in the cockpit, attached to the rudder pedal supports. Frequent access is required to check the sight gauges and to service the fluid reservoirs. Unfortunately, because of the location of the control units, the sight gauges are extremely difficult to read. However, the filler-bleeder plug is on the back of each control unit and, consequently, accessibility is poor and maintenance is time-consuming. A supersonic trainer is designed with external brake servicing and, as a result, routing brake maintenance can be performed much more efficiently.

Subsonic trainer: Aircraft static grounding receptacles are usually considered not to be replaced devices, even though maintenance experience has proven otherwise. Consequently, design and location often lead to inaccessible receptacles. On this aircraft, a receptacle is mounted inside the outboard leading edge of each wing and the leading edge must be taken off before a damaged ground can be removed and replaced. If the grounding receptacle was located differently (e.g., next to an access panel), such extensive removal would not be necessary. In many other USAF aircraft, replacement of grounding receptacles necessitates removal of fuel tanks or other structural assemblies. This inaccessibility increases man-hour requirements and in some cases manpower limitations may prevent defective grounds from being replaced at all.

Subsonic trainer: The aircraft has a forward retracting nose landing gear design which is susceptible to collapse if towed without proper support. A peculiar piece of support equipment,

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often referred to as a stiff knee, was developed to prevent collapse during towing. It is awkward to install because the maintenance specialist has to lie on the ground to position the stiff knee and insert safety pins. A few failures have occurred because of improper installation, but the primary objection to the procedure is the requirement for such a peculiar brace when other aircraft drag braces can be secured with a ground safety pin.

Subsonic trainer: Approximately 16-20 man-hours are required to remove the upper attachment bolt of the speed brake actuator. In order to remove and replace the upper speed brake attachment bolt you first have to remove both ejection seats and the actuator cover that is located between the right position rudder pedals. Since the rudder pedals are under the instrument panel, there is very little working space and the removal of the actuator cover attaching screws is a very time-consuming process. A modification to the access cover that included the cutting of access holes on each side of the attachment bolt has reduced some of the removal time, but it still requires excessive man-hours for the removal of one bolt.

Bomber: Space constraints and interference with equipment on the interior of the aircraft increases the amount of time required to change the pitot tube, angle of attack transducer, and temperature transmitter. The angle of attack transducer requires four to eight man-hours for removal. A fiberglass panel must be removed and the mechanic on the inside of the aircraft must blindly reach through control cables and air ducts to gain access to the transducer. In the period from October 1978 through March 1979 a total of 62 transducers failed on two models of the aircraft. To gain access to the pitot tube on the right side of the aircraft requires removal and replacement of a BNS junction box. This task requires five hours from the bomb-nav specialists and one hour from the instrument shop. The temperature transmitter is an external sensing bulb and the transducer is at station 340. Access is below the floor panels and the BNS remote unit modules power supply rack. During the October 1978 through March 1979 period on one model there were 11 failures which required 110 unscheduled maintenance man-hours. Another mode has an external access panel which facilitates the removal/replacement process. Desire the use of sensing devices that do not require internal access for removal; have an external access panel that would enable the technician to readily gain access to them; or are placed where internal access is not a problem.

Heavy air/ground fighter: Much of the maintenance cost on ejection seats is attributed to requirements for scheduled maintenance on seat mounted components that cannot be inspected without seat removal. Seat removal and replacement averages approximately one and one-half hours. It is virtually impossible to time change or inspect some seat mounted components, such as the catapult or the rocket motor, without first removing the seat. Many seat mounted components could probably be designed so they could be inspected without removing the seat. Adequate access is needed to permit removal and replacement of seat components without removing the seat.

Radomes: Operational data generally shows a large expenditure of man-hours charged to maintenance on fighter aircraft radomes. In the majority of instances, these man-hours are reported as "No-Defect" maintenance and are generated by the need to gain access to functional components, such as radar and antenna LRUs, installed behind the radome. The cost exceeds $2.00 per aircraft flying hour in logistics support cost. The opening or removal of some radomes can require several maintenance personnel to handle its bulk and weight. High surface winds, inadequate hold-open devices and complex hinge designs add to the service complexity and frequently require peculiar age such as jury struts. The area behind the radome must be weather proof and too often the seals are not capable of long life or easy replacement in this frequent access area. The action of opening and closing the radomes should be a one-man task. Desire the number of fasteners/locking devices be held to a minimum. Desire a hinge configuration that would support the opened radome in gusting wind conditions. Desire

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weather seals that can be easily removed and have a reasonable service life. Where practical, desire the number of functional components requiring access through the radome be held to a minimum.

Main instrument panel: Accessibility to equipment forward of the main instrument panel is usually restrictive. Examination of field data indicates that removal of one such panel to facilitate maintenance can take over six hours. Simplification of instrument panel removal or outside access doors will significantly reduce the logistics support cost and reduce maintenance time.

Very large transport: There is a small, quick-access door on the engine cowling door for servicing the engine oil tank. However, a similar door was not provided for CSD oil level inspection. A single maintenance person should be able to open an engine cowling door for quick easy access. If this is not practical, then provisions should be made to provide quick-access panels on the cowling door for components that require frequent access for inspections or servicing.

Very large transport: During depot maintenance many cracks are found in bulkhead fitting frame flanges at the chine web and outer chine attachments. Large 35 to 48 foot floor panels must be unfastened, jacked-up, and removed before the bulkhead fittings can be removed for repair of the chine web and the outer chine attachments. In addition, the cargo floor must be resealed after repairing and reinstalling the fitting to prevent fluids and debris from falling into the under floor area. Removal and reinstallation of the cargo floor panels can sometimes consume as much as 600 man-hours. If the large one-piece bulkhead fittings could be manufactured in sections, the section above the cargo floor and the section below the cargo floor could be removed independently and without removing floor panels, repairs would cost less and maintenance would be much easier.

Very large transport: Maintenance personnel have been hampered in their efforts to perform the required repairs on components located inside the engine pylon due to the limited accessibility provided. Engine ship personnel have a hard time trying to reach and replace the engine anti-icing valve located at the lower forward section of the pylon. This valve has failed 193 times in a six-month time period with 1858 unscheduled man-hours expended. In addition, other shop personnel are frequently required to enter the pylon area to perform maintenance tasks on cables, wiring, tubing, and hydraulic fittings. There are no side access panels. The only panel large enough to provide accessibility to the inside of the pylon is the top access panel; however, the pylon is about four to five feet deep to the bottom components. A tall thin person has to go in head first to reach the components, cables, wiring, and tubing and is limited to how long he can work hanging upside down.

Very large transport: Inspection of landing gear in flight is accomplished by use of two small windows for the main landing gears and a fiber optics viewer for the nose landing gear. Usually, the landing gears are inspected in flight to determine proper down lock, for the condition of the gears, and for inspection after damage or fire has occurred. The fiber optic viewer installed for the NLG is not effective, is limited to viewing a single component, and provides very poor visual quality. This is because of the inherent characteristics of the fiber optics. They become opaque when moisture enters the assembly as well as from wear and aging. A window near the NLG is desired instead of the fiber optic viewer.

Very large transport: A port hole or exterior fuselage access panel large enough for personnel access is needed for cleaning and inspection of corrosion, water, and hydraulic fluid. Because of the lack of these design features, it will continue to be a problem in the bilge area. Mechanics must crawl approximately 25 feet to reach the problem area. The crawl space is very small with several obstacles, ribs, formers, etc. obstructing the path. The problem is

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compounded in one area by urinal waste. As in other aircraft design features, urinal placement and removal of waste does not appear to have been a priority design item. Inherent corrosion problems have resulted. Although performance considerations and placement of aircraft components may necessitate unique locations, priority consideration should be given to latrine locations and easy access for cleaning and treating to avoid detrimental corrosion impacts.

Very large transport: Hydraulic lines routed under the forward cargo floor to provide hydraulic pressure to the NLG actuators sometimes develop leaks and must be repaired. In addition, access to this area is required periodically to inspect the hydraulic lines and other items. Access is by removal of large floor panels. Ease of access is inadequate. Removal of the large floor panels is time consuming and physically difficult because of the size and weight of the panels. It is desirable to have adequately stressed access panels provided directly in the floor to gain access to the hydraulic lines and other underfloor areas.

Ground attack: The mounting bolts for the wing outer panel have to be torqued periodically. The torquing of these wing bolts to 900 in-lbs requires the removal of a small access panel (12" x 18") located in the top of the main landing gear pod. The mechanic must be very small and must crawl up into the landing gear pod, make a 90 degree bend of the body, and squeeze down a four foot passage before torquing the bolts. This procedure is required every 50 flying hours.

Transport: The Doppler radar antenna cover is a stress panel because the compartment is pressurized. The compartment also contains the receiver-transmitter and other Doppler system components which require frequent access. In order to make these units more accessible, the antenna cover is attached with fasteners designed for quarter turn removal and installation. A threaded socket is incorporated in these fasteners which is designed so that a greater force than that afforded by the spring tension applied by a normal quarter turn fastener can be generated. In practice, although the fastener can be disengaged with a quarter turn, the threaded socket must be backed out so that the quarter turn may be reengaged. Many times the socket has corroded so that it is difficult to backout. In addition, backing the socket out too far or trying to engage the quarter turn by impact breaks the socket so that it must be replaced. Many man-hours are consumed in replacing these fasteners. Stress panels must, by their very nature, have high strength, multiple load path attachment to the structure which makes quick access difficult. Equipment requiring frequent access should not be placed behind stress panels. It is highly desirable to make such equipment accessible from inside the aircraft or place it behind quick access panels.

Transport: Modifications made to the aircraft especially by other than the original manufacturer have degraded or eliminated access to other equipment. The inventors have had additional equipment installed in front of them; the gaseous oxygen bottles installed in demoding certain special mission aircraft were placed in front of electrical terminal boards, and a wing mod completely eliminated the individual tanks refueling access for the auxiliary fuel tanks which were used for defueling also. Desire modifications consider the impact on maintainability of other systems existing in the aircraft.

Air supremacy fighter: Provisions were not provided for appropriate in-flight stowage of ground safety locks, pins, and missile covers. The practice is for the ground crew to remove the pins before taxiing out and retain them on the ground until the aircraft returns. However, the aircraft does not always land at the base of departure, and there is a risk that adequate pins will not be available at the destination. Stowage in the cockpit during flight is not practical because of the danger of handing up the items while directly in front of the engine intake with engines running. In addition, there is no adequately secure place in the cockpit for stowage. Ideally, the pins and covers should be stowed after engine start in a compartment safely accessible from the ground.

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One ECP to solve the problem was rejected because of the nearly $800,000 production and retrofit cost. Based on a field suggestion, a solution to the problem is expected which will provide a restrained compartmented stowage bag in an existing ground accessible compartment in the underside of the fuselage. With no structural change required, this solution is expected to be cost effective.

Cargo handling

Transport: An early model cargo winch used on some models of the aircraft is frequently damaged because the cable crosses over itself or the hook is wound onto the reel. The problem occurs when the cable is being retrieved without a load and usually results in damage to the housing, the cable, or both. The winch used on a large transport and some models of the transport has cable guides and limit switches. This winch has been very reliable and does not have any of the problems associated with the other type of winch which does not have cable guides and limit switches.

Transport: Excessive man-hours are spent cleaning the cargo compartment. The cargo rail system has several deep crevices and cavities which catch a great deal of debris. It is not practical to hose out the rails because the drains are inadequate and equipment in the bilge area could be damaged by backed-up water. A large transport has a similar but superior rail system. The rails are hinged on the outboard side and can be flush-stowed against the fuselage when not in use. The system requires minimal cleaning and does not have the debris problem associated with the other transport system.

Castings

Welded versus unwelded castings. Castings were received which had a potential strength reduction. The most serious deficiencies were due to unauthorized and undocumented welding, suspected incorrect weld material, welding techniques without established quality parameters, and suspected incorrect heat treatment. An analysis was made of the application of every casting and the safety implications of the failure of any given casting. The worst case strength reduction was determined and the uncertainty factor was calculated for each casting. Nine casting classifications were developed based on the expected results of a failure and each casting was identified with its appropriate classification. A sampling plan for each classification was developed and testing was accomplished to gather data on the condition of the deficient castings. Engineering recommendations were devised which detailed action to be taken on each casting or group of castings already installed on aircraft. The recommendations were: to continue flight operations without urgent inspection of some castings, remove and replace some castings; and perform special inspection of other castings. Several lessons were learned from this experience. One was that for critical items care must be exercised in the source selection process. The second was that receiving inspection, especially on critical items, must be thorough. A third was that an in-depth study that brings together the expertise and cooperation of all functional areas may be used to salvage expensive critical items since a thorough analysis of failure modes and safety margins may reveal latitudes not otherwise apparent.

Chafing of cables, tubing, and wires

Swing wing fighter bomber: An avionics cable is damaged (i.e., wires cut or wire coating shaved off, etc.) when the tail hook system is operated. The problem results because the cable and tail hook actuation rod are extremely close together and no protection is afforded the cable by a shield or cable jacket from a bolt used in the actuation assembly. Field personnel must cut out approximately two feet of cable and splice in a new piece using male and female connectors. One airplane has been fitted with aluminum tubing to protect the cable and has

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experienced no damage. Cables, wire bundles, and other similar materials must not be routed through areas where damage from moving parts is possible or else they must be protected (by metal conduit, tubing, etc.).

Wiring/tubing interaction: Electrical cables and steel lines carrying hydraulic fluid and gas should not be routed in close proximity. Chafing of the insulation on electrical wires may lead to arcing, subsequently causing a fire. When electrical cable clamps are mounted to the same, or adjacent, post as fluid line clamps, the close proximity can cause a fire. If cable chafing occurs, electrical arcing erodes the steel lines to the degree that internal pressure blows a hole in the line. Subsequent arcing ignites the fluid escaping from the line.

Heavy air/ground fighter: As a result of a notable increase in engine/engine bay fire/chafing occurrences in 1976, a conference was convened to determine what corrective measures were required. Recommendations covered a broad spectrum including extensive revision of applicable publications. These improvements also include reclamping the affected fluid lines and wire bundles in the engine bays to reduce chafing potential. Rerouting or repositioning of some components may be necessary to obtain adequate clearance at specific locations.

Swing wing fighter: During basic post flight inspection, a fuel tube was found leaking from a small hole. The hole was caused from the tube chafing against a hydraulic tube. Local inspection of 49 aircraft revealed eight additional chafed tubes.

Very large transport: An in-flight fire in a pylon was caused by chafed electrical wire sparks rupturing a hydraulic line and igniting hydraulic spray. Engineering study recommends rerouting wiring and fluid systems to reduce possibility of same type of failure recurring.

Air supremacy fighter: Inboard and centerline pylons problem of the preload post pin rubbing against wire bundle assembly and air pressure regulator tube assembly causing damage to both assemblies.

Large transport: Inspection TCTO was issued specifying inspection of specific thrust reverser lines. During inspection, oil residue was noted in area of other thrust reverser lines. Further inspection found lines on one engine had worn through. Inspection of four other engines found bad chafing on the same lines on each engine. Additional clamps solved the problem.

Clearance, alignment, and wear

Transport: Lack of sufficient clearance on the landing gear results in frequent interference and requires extensive man-hours to correct. While the main landing gear system is reliable, the close clearances frequently result in the main landing gear strut rubbing either the shelf bracket that serves as a gear down support and location guide, or the gear on the gear microswitch. Serious out-of-adjustment or failure conditions can result in stopping the gear travel, but the majority of problems stem from a slight rubbing contact between the components mentioned. Correction of these rub conditions usually requires minor adjustments to the shoe assemblies that locate the gear in the track assembly. This requires significant maintenance man-hours to jack the aircraft for retraction and adjustment of the gear. The adjustment may solve the majority of these problems. This problem has been solved by a change to afford sufficient clearance to allow for tolerance build-up due to uneven wear of attaching components.

Swing wing fighter bomber: Fire access doors on the aircraft have a high wearout rate and are not available as spares. Fire access doors in four panels are spring loaded and flutter in flight. This flutter causes quick wearout of hinges and doors. Hinges are frequently repaired in the sheet metal shop. The doors themselves are not provisioned. When a door is damaged beyond repair, the entire panel must be replaced.

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Wear of fastener holes: Frequent removal of fiberglass panels results in severe wear to the fastener holes. Fiberglass panels are used for aircraft weight reduction. Fiberglass is lightweight, structurally sound and is used in many non-load carrying areas. However, constant opening and closing of fiberglass panels elongates the fastener holes.

Swing wing fighter bomber: The cables and connectors to and from pivot pylons are subject to frequent damage during pylon mate/de-mate operations. The insulation is subject to wear because of in-flight pylon vibration. The pivot pylons mount both conventional and non-conventional ordnance. Two types of station program units (SPUs) are in each pylon to program the two types of weapons release: A conventional SPU and an aircraft monitor and control (AIAC) SPU. The pivot pylons require frequent change to tank pylons because of mission requirements. Several problems are associated with the pivot pylons. Cables and plugs connecting the pylon to the aircraft are frequently damaged during the mate/de-mate operation because they get hung up. Also, they are located in a hard to reach position and connecting them causes pin and cable damage. Another cause of cable damage is pylon vibration during flight. This results in the insulation being worn off the wires. Finally, SPUs located in the pylons were reported to be damaged because of frequent pylon change.

Swing wing fighter: The two upper shear pins for the aft engine door frame are difficult to align for insertion of the quick release locking pin. The aft engine door frame is attached to the main bulkhead with four shear pins. The upper shear pins are secured by a ball lock quick release pin which passes through both shear pins. With the engine installed, there is limited access to the holes through which the quick release pin must be installed. If an index mark (such as etched line) were installed on the head side of the shear pin, installation of the locking device would be made much simpler. Alignment or index marks on the visible side of components are needed to facilitate alignment of locking devices.

Very large transport: On the aircraft, some components do not fit as required. Mating parts, with misaligned holes, were apparently forced into place, inducing cracks. A significant number of cracks have appeared in the fuselage contour box beam assembly. Cracks have been found on ten airplanes at one fueling station and on seven airplanes at another. Repair times are 75 man-hours for cracks at the first station and 150 man-hours for cracks at the other. Total man-hours required have reached 1800. In addition, gaps between parts were not corrected with shims to prevent preloading, bending, and stress in those cases. The problem was primarily a tooling problem which affected early aircraft.

Complex and secondary structural components

Swing wing fighter bomber: There are several secondary structural components that do not have a critical function but do require frequent repairs or replacement. The following areas were noted by the using commands as examples of this on-going problem. First, the auxiliary flap system has minor functional benefits. However, this system has numerous interference problems as well as a complex rigging procedure that is usually inadequate. Because of these difficulties, TAC has reportedly deactivated the system; SAC frequently flies its aircraft without auxiliary flaps. In addition, a PRAM study was conducted by Sacramento ALC. The resulting recommendation was that the system be deleted. Second, the attaching former on the forward wing root teardrop fairing requires frequent replacement because of the thin material design. The problem is compounded by the fact that each former has to be match-drilled to fit each aircraft. (Some of the features of the airplane, e.g., auxiliary flaps and rotating glove, were added primarily to achieve U.S. Navy required carrier operation capability. As such, little could be done in the area of performance/structural complexity tradeoffs. The User, as well as the contractor, must weigh performance requirements/gains against development costs and anticipated maintenance.)

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Swing wing fighter bomber: The aircraft initially used translating (movable) vanes (one 12-inch vane for each flap at the trailing edge of the wings). The translating vanes were required because of performance goals and the narrow profile of the wings. As a result, the vanes interfere with normal flap movement when the flaps are retracted. A PRAM project was authorized to develop a permanent engineering fix to this problem along with other auxiliary flight control improvements which will simplify flap/slat rigging procedures. An engineering fix has been developed. The change will permanently attach the vane assemblies to the flaps and will significantly reduce maintenance on the flap/vane system. (Emphasis on performance requirements without limits or guidance regarding the means of achieving the performance have resulted in what appears to be unnecessarily complex systems that give only marginal performance gains for high maintenance upkeep costs.)

Ground attack: The entire throttle quadrant has to be removed whenever a switch on the throttle handle fails. This requirement to remove the quadrant causes excessive man-hours to be expended in removal, repair, replacement, and functional check of all components on the throttle quadrant. The throttle quadrant contains the following switches: speed brake switch, missile reject/uncage switch, right and left ignition button, communications "MIC" button, master exterior lights switch-missile video polarity, missile seeker head slew/track control, flap lever, throttle friction control, APU start switch, engine fuel flow norm, engine operator override, and L/G warn silence. There are about 33 maintenance actions involved in the removal, repair, replacement, and checkout of the throttle quadrant. The majority of the man-hours expended are in the throttle rigging, engine trim, and functional check/adjustment of the various switches on the throttle quadrant.

Subsonic trainer: The basic sheet metal airframe is easily maintained with minimal depot level support. The semi-monocoque design is frequently referred to as a sheet metal airplane by maintenance personnel. Although the airframe has some forgings and castings, it does not have exotic materials or components such as titanium, composites, honeycomb and chemmilleds skins. Instead, the structure is primarily formed sheet metal parts and extruded angles, hence the name sheet metal airplane. This type of construction is highly desirable, from a maintenance point of view, because the majority of the structural rework can be accomplished by field level maintenance (FLM) personnel. Using typical repairs in the structural repair manual (SRM), the FLM personnel can locally manufacture the repair parts and replace structural damaged parts without expensive depot level support.

Very large transport: The crosswind takeoff and landing capability is achieved by rotating the main landing gear to allow the pilot to point the aircraft into the wind. The rotation mechanism is a complex system of actuators, sensors, hydraulic plumbing and electrical wiring. This system is the most frequent cause of gear malfunction. Comparably sized commercial aircraft do not have this feature. The attendant actuators, sensors, wiring, etc. are complicated and drive up maintenance costs. The aircraft can safely operate with a 35-knot crosswind without the crosswind capability.

Corrosion

General: It is reasonably obvious that maintenance costs increase when corrosion occurs and that ease of access to the corroded areas also affects maintenance costs. Providing access for maintenance is one of the many considerations that are traded against other requirements, such as performance and structural integrity, during design efforts. To insure corrosion prevention considerations are included in the initial design, current systems require a corrosion prevention plan in accordance with MIL-STD-1568. This plan describes the approach to preventing corrosion and includes the establishment of a corrosion prevention team. This team has the responsibility to review preliminary drawings to insure corrosion protection techniques

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are adequate. This team also reviews the Corrosion Peculiar Technical Order (see MIL-M-38795) which identifies corrosion prone areas and defines maintenance actions. In addition, AFR 400-44 requires establishment of a Corrosion Prevention Advisory Board (CPAB) on all new major weapon systems.

Transport: Overboard draining of aircraft comfort stations allows waste to coat aircraft surfaces resulting in severe corrosion. The overboard draining of comfort stations, urinals, and relief tubes causes severe corrosion. To comply with existing corrosion prevention and remedial directives, excessive maintenance man-hours are expended in the constant actions necessary to prevent and deter this type of corrosion. Avoid overboard draining of comfort stations, urinals, and relief tubes. Some aircraft have incorporated chemical toilets with holding tanks to avoid this situation.

Crew entrance steps and ladders

Swing wing fighter bomber: High failure of crew entrance step pegs is caused by spline damage to the pegs and by solenoid failure. The crew entrance step pegs, which are also used to secure the entrance ladder, are unnecessarily complex. They are splined and run in and out of the step housing with a windowshade-type spring return mechanism. The pegs are spring-loaded to the extend position; they are held in the closed position by a retaining pin that is solenoid-operated from the pilot's compartment. The step pegs can be manually released from the outside by turning the manual release screws. The solenoids are disabled on many aircraft because of a high failure rate. The close tolerance of the step peg splines and the step housing results in pegs jamming when damaged by the ladder or foot.

Ground attack: The internal boarding ladder is difficult and unsafe to use. Structural failures of the telescoping sections and the rungs have occurred. In addition, the ladder has been jettisoned accidentally. It consists of a telescoping square tubular aluminum apparatus with rungs extending from the left and right sides. The pilot can deploy the ladder by energizing the rotor solenoid that opens the door panel. A ladder ejection spring pushes the ladder outward, allowing it to swing out and telescope to its fully deployed position. The ladder protrudes at an obtuse angle from the vertical axis of the aircraft. This angle imposes a bending load throughout the ladder sections and it has caused splitting of the lower tubular section and breaking of the rungs. The ladder is held open by a magnet which is not sufficient to prevent damage from ground winds which cause the door to flop. A failure of the step casting has occurred. Other problems include accidental jettison of the ladder and the absence of positive indication of ladder deployment. Some of the foregoing deficiencies have been corrected; the lower tubular section and the rungs have been strengthened. The pin ball locks that permit the jettison of the ladder during a scramble have been replaced with a solid bolt and nut.

Air supremacy fighter: The steps are telescoping, spring actuated, and mechanical locked devices. Repeated extensions (high bottoming out loads) have caused cracks and structural failures. The latching mechanism is not adequate since several inflight extensions have occurred. In two cases the steps failed and parts separated from the airplane fortunately missing the engine inlet.

Drain holes

Ground attack: The bottom cap assembly on the rudder fails from internal pressures caused by ram pressure on drain holes. The rudder on the vertical stabilizer contains a bottom cap assembly which is made of fiberglass. This cap assembly is hollow and has a drain hole at the bottom. During high speed operation, air is forced into the cap assembly via the drain hole causing the cap assembly to act as a baffle. When this happens, the trailing edge of the cap assembly tends to split open in order to relieve the pressure which has built up inside.

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Very large transport: Four drain lines are installed in each pylon. However, the existing drains incorporate finger screens which can trap foreign matter and unless carefully inspected, become plugged. To alleviate this possibility, an ECP has been approved to replace the finger screens with ones that are flush with the pylon lower surface and accessible for inspection and cleaning.

Engine/pylon removal/replacement

Ground attack: A positive feature of the aircraft is the engine/pylon design. The engine and pylon are designed to be handled as a unit which is attached to the airframe by three mounts and seven quick disconnects. Thus, all the tubing, hoses, fittings, and connections between the engine and pylon can be done in the engine shop and the entire engine/pylon assembly can be installed on the aircraft as a unit. The engine-to-pylon attachment is still a difficult and time consuming task, but it is much easier to perform in the shelter of the engine shop than out on the flight line. As a result of this design, an engine change can be done in as short a time as four hours.

Equipment location and retention

Liquid oxygen converter, life support systems: On several aircraft, the liquid oxygen converter is the highest logistic support cost item of the life support system. On some of the larger aircraft, the converter is located remote from the crew compartment at the far aft section of the fuselage in an area susceptible to high vibration. Excessively long distribution lines are not insulated from surroundings and result in increased generation of gaseous oxygen through agitation and heating. This situation causes increase in amount of venting through relief valves. Foreign materials, including moisture particles freezing in the lines and forming small ice crystals, enter the oxygen system during converter connection and also contribute to excessive venting until melted or blown loose. Maintenance actions consists of inspecting, servicing, and testing without any repair being performed. This is attributed to the excessive venting and the loss of oxygen being improperly diagnosed as leaks.

Supersonic trainer: As the result of a major accident, a need was recognized to modify survival kits so that they are retained in the seat bucket under negative g conditions. An ejection seat crew/kit retention strap (Crotch Strap) mod was developed.

External lighting (formation)

Swing wing fighter: The aircraft require lighting improvement for join-up and formation flying. An airplane was modified with four lighting fixes to determine the best lighting arrangements: (1) electroluminescent strip lights; (2) improved formation lights; (3) wingtip/glove light circuits; and (4) flood lights, OT&E was conducted. Lighting fixes (1) through (3) above constitutes total requirements. Three separate modifications will be processed to provide these lighting improvements.

Flight control (actuators, primary and secondary systems, surfaces, etc.)

Swing wing fighter bomber: The electrical backup system which operates the flap/slat extend/retract mechanism under emergency conditions does not include limit sensors. This permits actuation beyond normal limits with resultant structural damage. The normal hydraulic flap/slat actuation system has limit sensors which shut-off pressure to the hydraulic motors at the extremes of travel. The lack of sensors in the secondary system is conductive to damage to the electric motor and the flex drive shafts. The applicable technical order (T.O.) and the corresponding checklist include numerous warning and caution notes to alert maintenance personnel to use extreme caution when operating the system in the emergency mode. This

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attempt to preclude damage through warning notes would not be required if the aircraft were equipped with switches which would disengage the electric motor at the extremes of travel.

Swing wing fighter bomber: The flap asymmetry sensor is mounted on the number 4 flap segment of each wing. The sensor prevents flaps 1 through 4 from moving out of synchronization. Number 5 flap, however, has no asymmetry sensing device; consequently, hang-ups at the number 5 flap cannot be detected. Field activities have indicated that no in-flight control problems have been reported to date; however, post-flight inspections have revealed structural damage and flap separation at the number 5 flap. The reason the asymmetry sensor is located at the number 4 flap instead of the number 5 flap is that all swing wing fighter aircraft produced prior to the swing wing fighter bomber had only four flaps. When the swing wing fighter bomber was designed with an extra 2 1/2 feet of wing and a number 5 flap, the asymmetry device was left at the number 4 flap.

Large transport: Field reports have identified the following problems: Ailerons sticking in the up and down positions and inability to center, unwanted movements, and lagging and overshooting of manual and automatic input commands. These conditions are caused by inability of the ailerons to overcome input linkage friction and control valve operating forces at cold temperature in the presence of contaminated hydraulic fluid, which also tends to compress the input override bungee.

Fuel filter retaining strap

Tanker/transport: A flight mishap was caused by the cap of the main fuel filter separating from the filter body assembly. This was a repeat of a similar mishap in 1959. A retaining strap and cable assembly was installed over the cap and body assembly to prevent this from occurring. Since that time no cap separations have occurred; however, testing of the retaining strap and cables has revealed that if the filter retaining rod breaks below the filter cap, the retaining strap will slide off the fuel filter cap and 10 PSI internal fuel pressure will cause the cap to separate from the filter body assembly. Field level installation of an improved retaining strap and cable assembly on main fuel filters is being done (1981).

Fuel vents

Air superiority fighter: The fuel vent on the aircraft is flush with the bottom of the left wing. When the aircraft is on the ground, changes in ambient temperatures can cause fuel to expand and be vented from the fuel vent. Surface adhesion causes the fuel to cover the entire bottom of the wing. The area covered by the dripping is larger than any drip pan and creates a fire hazard.

Heavy air/ground fighter: A mishap investigation board identified a problem in the aft fuselage fuel vent line system. There were four more mishaps involving aft fuselage fires and damage to the aft section of the aircraft. A test program was performed as the last phase of an evaluation to insure the improvements would solve the existing problems. The test program was completed and a modification was made to enlarge the bulkhead holes through which the vent line passes, relocate the pencil drain in the vent system and install brackets to stiffen the vent line.

Ground refueling

Subsonic trainer: Over-the-wing refueling is a high man-hour consumer and has contributed to fuel system contamination problems. Two people are required for refueling because both wing tanks must be filled simultaneously to preclude damage caused by fuel imbalance. Single point refueling requires only one person and can use higher flow rates, resulting in significant manpower savings. The over-the-wing filler ports are a source of fuel contamination. Paint and

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metal chips are knocked into the tanks by the filler nozzles and cap retainer lanyards and nozzle basket ports are frequently broken off or dropped into the tanks. The rate of fuel tank contamination occurrences on this subsonic trainer is 10 times that of a supersonic trainer. Review and include as applicable the Standardization Agreement 3212ASP on diameters for gravity filling orifices.

Hoist/cable guides

Hoists: One of the most difficult line replaceable units (LRU) to handle in the avionics intermediate shop (AIS) is the radar antenna. Because of the weight (approximately 80 pounds) and the bulkiness of an antenna, many times damage is caused just in transporting and mounting the unit into the fixture. In one of the AIS, the hoist/cable required constant tension to prevent the cable from slipping off the reels. When this occurred the antenna would have to be manually lifted off the fixture, the cable reinstalled on the reel, and then remounted onto the fixture. The need for cable retention guards and guides applies to airborne hoists as well.

Impact bags, parachutes, and pressure bottle installations

Swing wing fighter bomber: The escape capsule impact bag, the stabilizer brake chute, and the recovery chute are time change items requiring periodic replacement. All three items are compressed and sealed in their shipping containers. Once the containers are opened, the items immediately start to swell. The impact bag in particular will swell to the point that it must be compressed into position with a jack stand if it is not installed in the aircraft within thirty minutes. Installation of all three items takes three days.

Swing wing fighter: Fuel was discovered leaking from the nose wheel well. Investigation revealed the left hand pressure source bottle for the impact attenuation bag had exploded causing extensive aircraft damage. The F-1 fuel tank bulkhead had been punctured, the left hand seat structure attaching points had broken and forced the seat forward, and the adjacent outside aircraft skin was bulged outward. Burst tested six pressure source bottles. All exceeded virgin burst requirements. Burst testing of 15 damaged bottles removed in accordance with TCTO. Problem still under investigation.

Interchangeability

Swing wing fighter bomber: The teardrop panels, like many other panels, come from supply as undrilled blanks. Since the aircraft structure normally warps during its life cycle, predrilled panels usually will not fit. The blank panels are drilled in place to fit the existing structure. For this reason, panels from one aircraft will seldom fit any other aircraft. In the case of the teardrop panels, the panels attach to a heavy forging which is not subject to warping. Predrilled panels would have been practical in this case.

Very large transport: Landing gear and brake failures have occurred as the result of cross-connected hydraulic lines. One of the landing gear retracted, both the normal and emergency systems failed to lower the gear. The normal system was inoperative because of a broken linkage between the unlock actuator and the over-center mechanism that locks the gear in the retracted position. A separate emergency lock/unlock actuator is included in this design but the hydraulic lines to it were reversed. Hence, when the emergency geardown system was activated, pressure was applied to drive the mechanism firmly into the locked (up) position. One would expect such a condition to be discovered by required checkout procedures following any maintenance on the system. Although such checks were performed, the gear functioned normally during the tests in spite of the cross-connected hydraulic lines. In flight, however, the timing of the door opening and loads on the system were changed. As a result, the gear remained in the up position. A similar incident occurred involving the brake system. During

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maintenance, hydraulic lines were inadvertently crossed on both main landing gear bogies. Later, maximum braking was applied upon landing from a functional check flight. The anti-skid system sensed a nonskid condition on the "A" pair of wheels on each bogie and increased the braking pressure. Because of the reversed lines, this pressure increase was directed to the "B" pair of wheels. The system sensed the impending skid of the "B" wheels and relaxed the pressure in the "B" lines which were misconnected to the "A" wheels. The end result was no braking on the "A" wheels and four blown tires on the firmly locked "B" wheels. Thus, the misrigged system caused the condition it was intended to prevent.

Transport: Two jacks are required to change a flat tire. The first jack is needed to lift the strut high enough for a 35 ton jack to be inserted. The second jack will then raise the aircraft so that the tire can be replaced.

Very large transport: Non-permanently installed jack pads increase maintenance man-hours, require 780 record maintenance, and result in the loss of jack pads and attaching parts. Jack pads were not originally installed as a permanent part of the airframe, subsequently, the pads were permanently installed after a test proved that jack pads exposed to the airstream did not result in an appreciable increase of fuel used due to drag. This action reduced 780 equipment record keeping time. Maintenance man-hours required to install and remove the jack pads whenever the aircraft was jacked were eliminated. In addition, jack pad and attaching part losses were also eliminated.

Landing gear position change

Air supremacy fighter: The original location of the MLG was changed to enhance the location of center-of-gravity relative to the MLG and the crosswind landing characteristics of the aircraft. The change incorporated an extended drag link to effect this enhancement rather than a redesign of the MLG. The change, when incorporated, caused geometric misalignment of the MLG wheels resulting in excessive MLG tire wear and maintenance support cost.

Landing gear position locks and servicing

Swing wing fighter: Slight (5-7 percent) overinflation of the gear struts will prevent the main gear from locking in the retract position. The landing gear strut servicing procedure uses air pressure in conjunction with strut extension for proper inflation of the shock struts. The strut extension is measured in one-eighth inch increments and the air pressure is held to plus or minus twenty-five pounds per square inch. The gage used for this procedure has a range of 0-4000 pounds and the dial face is marked in 100 pounds increments which makes accurate air servicing very difficult and almost impossible to meet the plus or minus 25 pound requirement.

Subsonic trainer: The main landing gear cannot be lowered by either the hydraulic system or the emergency air system unless the main gear door uplock mechanism can be released. The conventional tricycle landing gear retracts and extends by power from the aircraft hydraulic system. The inboard main gear doors are actuated hydraulically and are operated by a sequencing valve in the landing gear system. This valve synchronizes opening and closing of the doors with extension and retraction of the main gear. The inboard main gear doors engage the uplock hooks. The nose-wheel doors are actuated open and closed by mechanical linkages which are connected to the nose gear. The landing gear emergency extension system consists of an emergency gear T-handle and an emergency air bottle containing 2000 +250 psi of air. Activation of the emergency system directs air to the actuators to open the main gear doors and to lower the landing gear when a failure occurs in the hydraulic system. If mechanical failure occurs which prevents operation of the main gear door actuator or the door uplock release mechanism, the main gear cannot be extended. Consideration should be given to a manual

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uplock release, free-fall emergency landing gear extension system, as one alternative for aircraft such as a light trainer.

Attack fighter: The MLG uplock system has experienced problems due to difficulties in maintaining proper rigging. This condition results in failure of the uplock structure and subsequent failure of the gear to extend. Cause of the problem is abnormally large loads being transferred into structure not designed to withstand such loading. Three gear up landings and numerous maintenance actions have resulted from this condition. A TCTO to replace MLG restrictor with a design allowing for slower gear retraction and resulting smaller loads has been issued.

Evacuation transport: During free fall testing of the NLG, it was discovered that down and locked may be indicated prior to the gear downlock mechanism being overcenter (safe).

Lost antennas

Transport/large transport: Aircraft antennas are bolted to the outer fuselage skin. The loss of an antenna becomes significant when cabin pressure is lost through the hole created by the loss of the antenna. For example, an airplane was cruising at 39,000 feet when a rapid loss of cabin pressure was detected. The pressure was lost through the hole left when an antenna came off in flight. Aircraft antennas are subject to ground damage, vibration, shock, and internal/external pressures while in flight. The cabin pressure tends to force the antenna away from the aircraft and results in advertent depressurizations when the entire antenna is lost. Cabin pressure forces should tend to hold the antenna in place rather than force it loose. External removal and replacement should also be a consideration.

Moisture intrusion

Subsonic trainer: Rain, melting snow, and other forms of moisture seep into the avionics compartment of the aircraft during foul weather causing premature avionics failures. This problem is further complicated because of the design of compartment covers, which raise up and allow water to run off into the compartment. The moisture problem is attributed mainly to the design of these covers and associated rubber seals.

Swing wing fighter: The canopy seals on the cockpit canopy are depressurized when the power is off, as it is when the aircraft is parked. Originally, when these seals were depressurized rain leaked through, causing corrosion and damage to electronic components, such as short circuits. Subsequently, a round tubular shield was placed around the cockpit periphery outside of the original seal. This blocked any moisture from penetrating, even when the pressure seals are depressurized.

Ground attack: Thin panels used on avionics bays do not prevent water intrusion. When sealant is applied to the panels, the panels deform and eventually fail with fasteners pulling through the panels. One factor in the design was to have thin, lightweight, flush panels on all bays. Thin panels do not prevent water intrusion very well and are very susceptible to deformation. The deformation problem is increased when seals are added to prevent water intrusion. Space for the seals could have been allowed and still kept the panels light in weight, thin, and flush.

Overload (NZW) warning

Overload warning system: Although the aircraft mounted accelerometers give accurate "g" load readings, they do not consider weight or altitude for a true depiction of aircraft load conditions. The acceleration limits of one fighter are 5.1 g at 53,300 pounds and 7.3 g at 37,400 pounds. The aircraft has the lowest tolerance to excessive "g" loads occurring in the area of 20,000 feet pulling 7.5 g at 40,000 feet and less than 37,000 pounds would indicate the same on the

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accelerometer counter at 7.5 g at 20,000 feet at a weight of 53,000+ pounds. Although instrument indications would be identical for each, the latter would be more critical, affecting the fatigue life of the airframe. Consideration should be given to developing and installing an overload warning system in future high performance air combat fighters.

Paratroop seats

Transport: The paratroop seats are designed in segments to facilitate handling. Segments are connected by 16 inch nylon zippers to form a bench. The zippers frequently fail under the loads applied during normal use and handling. Replacement zippers are available, but replacement requires removal of two seat segments. Many times the whole seat unit is replaced because of zipper failure. In either case significant man-hours are required.

Redundant routing of cables, lines, and wires

Very large transport: Failure of the T-tail flight controls was caused when the aircraft pressure door broke loose in flight and severed the hydraulic lines, electrical wires, and cables to the hydraulic power packs that operated the flight controls. Because primary and secondary hydraulic lines were routed together along with electrical circuits for trim control, failure of the control cables was compounded by loss of any control of the primary and secondary flight surfaces in the empennage. This problem has been minimized by rerouting and separating the redundant flight control system hydraulic lines, electrical wires, and cables. Rerouting has minimized the potential for redundant system loss.

Swing-wing bomber: The aircraft was flying a designated low level, high speed leg of a simulated bombing training mission. A bird penetrated the aircraft structure through the inboard side of engine three's boundary control gutter wall. Critical hydraulic lines, fuel lines, and numerous electrical lines, cables, and junction boxes were grouped together in this bird impact penetration vulnerable area. The requirement to separate critical lines, such as hydraulic, fuel, and electrical is to be made applicable to all airframes, particularly those that are to be used at low level for extended periods of time. This requirement to eliminate the grouping of critical lines and subsystems that do not have separated redundant counterparts is to be made applicable regardless of the size of bird required in 3.2.24, Foreign Object Damage (FOD).

Refueling overpressure

Tanker/transport: Two aircraft are barred from aerial refueling with the aircraft due to unsafe conditions. Some aircraft are restricted to only partial refueling with the aircraft due to unsafe/hazardous results if the receiver aircraft obtains full tanks during refueling (i.e., receiver aircraft fuel tanks will rupture due to tanker fuel pressure).

Aircraft that are designed to receive fuel during inflight refueling operation must have provisions to preclude overpressurization when the fuel tanks reach the full condition.

The refueling system on tanker aircraft must include pressure regulation to preclude unacceptable pressure surges in the event of failure of pressure relief systems on receiver aircraft.

Transport: Number one fuel tank over pressurized causing internal and external structural damage.

Review and include as applicable the Standardization Agreement 3681PHE on criteria for pressure fueling of aircraft.

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Reliability

Swing wing fighter bomber: The tail light is a high failure item. Many times, two or more bulb replacements are required after flight. The tail light assembly is isolated to absorb approximately ten g's of vibration. Vibrations as high as 50 g can occur in the tail section. Vibrations of this magnitude can snap a bulb filament. The use of adequate vibration isolation and the use of non-filament high reliability type light bulbs for all light assemblies should be considered.

Swing wing fighter bomber: The anti-collision lights are retracted when they are not in use. The retraction mechanism causes many failures and significantly lower reliability in comparison with fixed lights. The drag benefits of having the lights retracted appear to be minuscule. During normal operations the lights are always extended and on. It appears that the performance benefits of the retractable lights are more than offset by the increased cost and lower reliability of these units compared to fixed lights. Streamlined, fixed, anti-collision lights instead of retractable lights should be considered.

Very large transport: Fittings in the hydraulic return lines in areas of high flexing (wings and pylons) are failing due to flange separation in the self-aligning part of the tube to fitting interface. They were designed to allow angular misalignment caused from wing and pylon flexing and linear expansion/contraction from pressure surges and thermal effects. A fitting consists of a nut, stainless steel locks or snap ring, O-ring, and two half moon sleeves made of stainless steel or aluminum (depending on where in the hydraulic return system they are used--the stainless steel sleeves are used in areas of higher vibration). The function of the half moon sleeves is to fit over and around the flanges of the two connecting tubes to permit the tubing to slip during flexing. Some of the problems with the fitting can be attributed to the fitting design; others to the thin walled tubing that is used with them. Examples of reported failures are: cracked half moon sleeves (aluminum), broken tube flanges, cracked nuts, holes in tubes caused by rubbing the half moon sleeves, and holes at tube anchor points in high flexure areas. Some aircraft have not experienced this problem. A large transport uses standard AN fittings in the high flex areas with thicker walled tubing. On a tanker/transport, the straight swivel slip coupling is used at strategic locations to absorb the expansions and movement of the hydraulic lines. An air/ground fighter used flexible line segments and rigid fittings.

Repair of lightweight tubing

Ground attack/air superiority fighter/electronics: These aircraft use high strength 21-6-9 instead of the widely used 304 1/8 tubing as a weight savings. The weight savings on the fighter was 18 pounds and 108 pounds on the electronics aircraft. The major difference between the tubing is 21-6-9 has thinner wall structure but is stronger. The 304 1/8 stainless steel tubing was used on earlier aircraft prior to introduction of 21-6-9 and is presently available in the field. By using the 21-6-9 tubing, new tooling and special mandrels were required since the tooling for the 304 1/8 tubing was too soft for bending 21-6-9 tubing. To alleviate procuring additional tooling for bending 21-6-9 tubing, AFLC has authorized the use of 304 1/8 stainless steel as the repair item for failed 21-6-9 stainless steel tubing. Authorization for repair of 21-6-9 tubing with 304 1/8 should be included in each technical order and document applicable to performing tube replacement.

Taxi damage

Large transport: During taxi for takeoff, the aircraft made a right turn onto the taxiway. During the turn the aircraft right wing tip contacted a building inflicting damage to approximately 18 to 24 inches of the right wing tip. Fuel from the number four main fuel tank spilled. The engines were shut down and the crew evacuated the airplane.

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Toxic materials

Heavy air/ground fighter: An aircraft was lost when its cockpit filled with smoke and the crew ejected. The smoke, which prevented all outside vision and totally obscured the instruments, was generated by the polyvinyl chloride (PVC) lining of a cockpit insulation blanket. A failed bleed air line clamp allowed high temperature air to impinge on the outside wall of the cockpit. The blanket which was in contact with the inside cockpit wall began to smolder and gave off the dense smoke. In an attempt to clear the cockpit sufficiently to fly the aircraft, the crew jettisoned the rear canopy. The increased air flow in the cockpit, however, fanned the smoldering blanket into a small fire and increased the density of the smoke. All visual references were lost and the crew ejected. PVC is a highly versatile material which has definite cost advantages. However, the hazards associated with this material must not be overlooked. Although not highly flammable, it will give off toxic fumes, dense smoke, and burn when sufficiently heated. Its use in occupied areas of an aircraft, and especially the cockpit, should be seriously questioned. Alternate materials with better high temperature characteristics are available and, although pound-per-pound costs may be higher, may provide the optimal solution. In this mishap, it was the smoke that cost us the aircraft, not the fire. Elimination of the material which generated the smoke is the only completely satisfactory answer. Solutions which center on potential ignition sources exist. The materials used in aircraft interiors are to comply with the PVC restrictions of MIL-STD-1587.

Upper torso crash restraint

Evacuation transport: The present forward and aft attendance seats do not provide upper torso restraint to protect medical crew members from crash impact.

Observation: An aircraft on a tactical range mission crashed during maneuvers. The aircraft was observed to fly past the target, initiate a pull-up and aggressive right turn greater than 90 degrees to target. Pilot made an abrupt pull-out in an estimated 30 degree nose low delivery. The aircraft struck the ground short of the target. The accident board investigation has been completed. A recommendation for a feasibility study to determine how to reinforce the seat base and shoulder harness attach points to increase crash survivability was established by engineering.

Walking on structural components

Very large fan jet engine cowling: The inlet cowling is constructed in large segments made of light-weight aluminum. These segments are easily damaged when maintenance is performed on or around them. The fan section has an inside diameter of approximately seven feet. This large opening allows maintenance personnel to stand inside the cowling and work on the fan assembly. Damage to the cowlings results from tools being dropped on them and people walking on them. Another problem associated with the large inlet cowling is due to its design and size. To provide access to components under the cowling, large sections must be removed. The sections are riveted together and the rivets must be drilled out to separate the sections. These removals contribute to the wear and tear on the inlet cowling. Maintenance data shows that in a 6-month period, 335 failures were reported and 13,779 maintenance man-hours expended. The majority of the failures were attributed to cracks. Cowlings should be adequately constructed to withstand maintenance actions imposed on and around them. Segment size should be reduced to facilitate easy removals. This applies to similarly exposed airframe components as well.

A.4.3.20 Other design and construction parameters. (___)

Analyses, inspections, and tests shall verify that the requirements of 3.3.20 are met.

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VERIFICATION RATIONALE (A.4.3.20)

Verification of other design and construction parameter requirements is needed to assure that these added requirements are met and that the operational use of the air vehicle is not degraded or maintenance requirements increased.

VERIFICATION GUIDANCE (A.4.3.20)

Other specific design and construction parameters, conditions, and situations must be identified and listed in the same way and sequence as in 3.3.20. Required analyses and tests are to be defined for each specific design and construction requirement.

VERIFICATION LESSONS LEARNED (A.4.3.20)

See Requirement Lessons Learned under 3.3.20 which is applicable to both 3.3.20 and 4.3.18.

A.3.4 Structural loading conditions.

The airframe operational and maintenance capability shall be in accordance with the following structural loading conditions in conjunction with the detailed structural design requirements of 3.1 and the general parameters of 3.2.

REQUIREMENT RATIONALE (A.3.4)

The purpose of this requirement is to insure that the critical loading conditions and associated loading distributions are established in accordance with the specified structural design criteria.

REQUIREMENT GUIDANCE (A.3.4)

During flight operations, ground operations, and maintenance the airframe will be subjected to forces such as aerodynamic, inertia, thrust, and mechanical. The determination of these forces is required to establish the external and internal loads which in general are influenced by structural flexibility and which the airframe must sustain during its expected usage. Within the ground rules of the specified structural design criteria, it is necessary to define the structural loading conditions and load distributions which are required to generate design loads. The loading conditions shall be categorized as flight loading and ground loading conditions.

REQUIREMENT LESSONS LEARNED (A.3.4)

Particular care should be exercised in defining the structural loading conditions and load distributions which are used to design the airframe since these items directly influence the performance and structural reliability of the airframe.

A.4.4 Structural loading conditions.

The loading conditions and criteria of 3.4 shall be detailed and included in the detailed structural criteria of 3.1.1. Analyses and tests shall verify that the airframe can operate in the flight and ground environment associated with the operational use as required by 3.4.

a. Analyses.

(1) Flight loads analyses. ___________________.

(2) Ground loads analyses. ___________________.

(3) Aerodynamic heating analyses. (_____) ___________________.

(4) Other analyses. (___) ___________________.

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b. Wind tunnel tests.

(1) Force model tests. (___) __________________.

(2) Pressure model tests. (___) __________________.

(3) Aeroelastic model tests. (___) __________________.

(4) Other model tests. (___) __________________.

c. Flight and ground tests.

(1) Flight loads measurements. (___) __________________.

(2) Ground loads measurements. (___) __________________.

(3) Temperature measurements. (___) __________________.

(4) Other measurements tests. (___) __________________.

VERIFICATION RATIONALE (A.4.4)

This verification task is required to assure that the structural loading conditions and criteria of 3.4 are appropriately determined and formally established. A comprehensive loads program which consists of analyses and tests is required to identify potential critical aircraft components which will be sensitive to particular forms of operational loading environment, and to verify the accuracy of the analytical prediction techniques. Validation of the prediction techniques will enhance their utility in application to other service environments for loads determinations. Extensive instrumentation/testing of aircraft also reveals previously unknown physical phenomena and assists in its understanding, thereby leading to the development of improved loads prediction techniques.

VERIFICATION GUIDANCE (A.4.4)

The establishment of detailed loading conditions will assure a high level of structural reliability without undue conservatism which has the inevitable consequence of excessive structural weight and degraded performance. Detailed loading conditions included in the detailed structural criteria of 3.1.1 and 4.1.1 will permit approval control over the design early in the design cycle and form the basis for the determination of design loads. The analyses shall be of sufficient scope to establish the service loads and maximum loads which the aircraft will experience during operations specified under 3.4. The blanks for flight loads and ground loads analyses shall be completed by specifying the applicable flight loading conditions of 3.4.1 and ground loading conditions of 3.4.2. For aerodynamic heating and other analyses, define the applicable loading conditions. The wind tunnel tests shall be performed over a wide enough range to insure coverage of the design operating environment specified in 3.2 and 3.4. For force model, pressure model, aeroelastic model, and other model tests, define the proposed test configurations and conditions. Flight and ground tests shall be extensive enough to substantiate the design loads analyses and to demonstrate aircraft structural integrity for the critical loading conditions. For flight loads, ground loads, temperature, and other measurement tests, define the proposed test configurations, conditions, instrumentation, and calibration procedures. AFFDL-TR-76-23, Volumes I-VII; AFWAL-TR-80-3036, Volumes I-III; FTD-MT-64-269; AGARD Report 113; AGARD-AG-160, Volume 7; NACA TN 1178; NACA TN 1140 and ASD-TR-80-5038 provide some insight in applying the loads analyses and verification requirements.

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VERIFICATION LESSONS LEARNED (A.4.4)

A comprehensive flight and ground test program which detailed the requirements for aircraft structural integrity flight and ground evaluation and demonstration was previously specified in MIL-A-8871A. The overall value of strict adherence to these requirements has been demonstrated on numerous test programs. On more than one occasion, new critical loading conditions were identified early in the program as a result of this comprehensive approach. These critical loading conditions were then included in subsequent full scale static test programs.

Several aircraft have required extensive redesign of major components to assure compliance with the structural design requirements. Wing tip mounted missiles were lost from an air superiority fighter on two occasions when jet wakes were encountered. The causes were identified as high wing tip accelerations in combination with substandard cast fittings used to attach the launchers to the wing tips. The horizontal tail carry-through structure of a bomber failed during low level operations. Failure was attributed to asymmetric loads exceeding the strength established by the arbitrary 150-50 distribution of the then current specification.

Calibrated strain gage systems and pressure transducer systems have been used successfully to measure flight loads. However, data processing to determine net loads from aerodynamic pressure measurements have been very expensive and time consuming. Because of data processing requirements, this approach to load measurement is not very amenable to inflight real time monitoring. If the use of aerodynamic pressure measurements is the preferred or required method, the addition of some calibrated strain gages to provide real time monitoring of major component total loads has been found useful. Additional details comparing flight load measurements obtained from calibrated strain gages and pressure transducers are provided in ASD-TR-80-5038.

The load carrying capability of landing gear for the taxi mode of operation has generally been determined by the 2.0g or 3.0g specified load criteria depending on whether the main gear or nose gear design is being considered. Drop testing of the landing gear strut verifies the energy absorption capability of the strut and provides for the validation of its load/deflection or airspring curve. It has then been assumed that the strut, for purposes of analysis and operation, will behave in accordance with the manufacturers plotted airspring curve if the strut has been serviced in accordance with the manufacturers instructions. Recent flight test programs with transport aircraft performing taxi and braking tests on low bump amplitude AM-2 metal repair mats has demonstrated conclusively that documented drop test strut data cannot be relied upon to accurately predict landing gear taxi loads and strut deflections. These tests demonstrated that cycling of the struts due to surface roughness resulted in degraded strut damping performance, and in some instances resulted in bottoming of the struts thereby providing the potential for tire, strut, or airframe damage in spite of the fact that pre-test and post-test examination showed the struts to be properly serviced. Strut performance degradation was attributable to air/oil mixing in the landing gear struts. This same test program revealed unexpectedly high lateral and fore and aft accelerations of an outboard engine pylon, attributable to excitation provided by wing bending and anti-skid cycling respectively. The identification of previously unknown critical conditions was the result of a comprehensive loads program utilizing thoroughly instrumented aircraft.

A.3.4.1 Flight loading conditions.

Flight loading conditions are essentially realistic conditions based on airframe response to pilot induced or autonomous maneuvers, loss of control maneuvers, and turbulence. These realistic conditions shall consider both required and expected to be encountered critical combinations of

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configurations, gross weights, centers of gravity, thrust or power, altitudes, speeds, and type of atmosphere and shall be used in the design of the airframe. Flight loading conditions shall reflect symmetric and asymmetric flight operations and are established for both primary and secondary structural components by careful selection of flight parameters likely to produce critical applied loads. Symmetric and asymmetric flight operations shall include symmetric and unsymmetric fuel and payload loadings and adverse trim conditions. The following conditions reflect required flight operations capability of the airframe.

REQUIREMENT RATIONALE (A.3.4.1)

The purpose of this requirement is to insure that all applicable flight loading conditions are established in accordance with the detailed structural criteria of 3.1.1.

REQUIREMENT GUIDANCE (A.3.4.1)

Flight loading conditions include those resulting from maneuvering the aircraft, atmospheric turbulence or failure of an aircraft part or equipment. In case of system failure, the aircraft must have the capability to withstand the resulting maneuvers, plus the corrective action taken by the pilot treated as limit loads. The flight loading conditions should be carefully established since these conditions are used to determine the service loads and maximum loads which the airframe must sustain during its expected usage. Service loads shall be established for the repeated loads sources specified in 3.2.14.3. The maximum loads should be distributed to conservatively approximate or closely represent actual loading conditions. Redistribution of these loads must be accounted for if significant distribution changes can occur under structural loading. Airload distributions should be determined by use of acceptable analytic methods or by appropriate wind tunnel test measurements. In general, flight loading conditions should be realistic conditions based on airframe response to control system induced maneuvers and turbulence.

REQUIREMENT LESSONS LEARNED (A.3.4.1)

The flight loading conditions should be established by careful selection of flight parameters likely to produce maximum applied loads. The design speed envelope and V-n diagrams represent the starting point for computation of most critical flight loading conditions. Wing, fuselage, horizontal tail, and vertical tail design load conditions are selected on the basis of maximum shears, bending moments and torsions at panel point locations. Maximum wing shears and bending moments are generally established by combining minimum wing weight with maximum positive and negative airloads. Maximum wing torsions are likely to occur from large deflections of control surfaces such as ailerons or flaps. Stores located near the wing tip or large protuberances on the fuselage are likely to have the greatest effect on wing loads. Maximum fuselage vertical shears and bending moments are usually established by neglecting vertical airloads. Maximum fuselage lateral shears and bending moments are usually established by determining maximum lateral airloads. Maximum aft fuselage torsions are likely to occur from rolling maneuvers which produce large differential tail loads. Maximum horizontal tail loads are generally established by determining conditions which require maximum balancing tail loads. Maximum horizontal tail torsions are likely to occur from large deflections of control surfaces such as elevators. Rolling maneuvers with heavy wing mounted stores usually produce large tail loads. Maximum vertical tail loads are likely to occur from rolling and yawing maneuvers which produce large sideslip angles. Maximum vertical tail torsions may occur from maneuvers involving large rudder deflections. Flight loading conditions for primary and secondary structural component were previously specified in MIL-A-008861.

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A.3.4.1.1 Symmetric maneuvers.

These maneuvers shall be performed with and without a ________ roll rate command. The analyses shall include tolerances to account for known discrepancies such as air data system errors, attitude errors, control system lags, fuel sequence, actuator performance, and rigging. These tolerances shall be applicable until the loads flight test data has validated the maneuver simulation.

a. Steady pitching maneuvers of ___________________.

b. Abrupt pitching maneuvers with longitudinal control displacements of ____________.

REQUIREMENT RATIONALE (A.3.4.1.1)

Symmetric maneuvers represent common operational maneuvers and are a major design load source on primary and secondary structure for all category aircraft. Symmetric maneuvers for design shall include (but are not limited to) those listed in the requirement guidance section below.

REQUIREMENT GUIDANCE (A.3.4.1.1)

The symmetrical maneuver conditions shall be accomplished with and without a specified roll rate command above 80% maximum symmetric N_Z to provide acceptable roll capability throughout the specified flight envelope. The roll capability above 80% N_Z should be established by sensitivity studies which require approval of the procuring agency. A minimum of 50° per second roll rate command is recommended for A, F, TF, O, and T aircraft and a minimum of 30° per second roll rated command is recommended for all other aircraft. The roll rate command shall be maintained throughout the symmetrical maneuver conditions. The value of each tolerance used in the analyses shall be specified. For steady pitching maneuvers define the maneuver requirement in terms of required parameters, 3.2 and 3.4 and rational combinations thereof. For example, steady pitching maneuvers of all points on and within the maneuvering envelope bounded by O, A, B, C, D, E, and O of the V-n diagram for symmetrical flight shall be accomplished. V-n diagrams similar to that depicted in figure 10, with particular attention being paid to the notes, shall be provided for combinations of altitude, air vehicle weight, configuration, and other pertinent parameters. For abrupt pitching maneuvers also define the applicable requirements. For example, abrupt pitching maneuvers with longitudinal control displacements of the triangular and rampstyle displacement-time curves similar to that depicted in figure 11 shall be accomplished for all points on and within the maneuvering envelope bounded by O, A, B, C, D, E, and O of the V-n diagram for symmetrical flight. Load factor at each airspeed shall be attained as specified in steps (a) and (b) for all center-of-gravity positions, and shall also be attained as specified in step (c) for the maximum aft center-of-gravity position:

a. By a longitudinal control movement resulting in a triangular displacement-time curve as illustrated by the solid straight lines of figure 11(a) provided the specified load factor can be attained by such a control movement; otherwise by the ramp-style control movement illustrated by the dashed straight lines of figure 11(a) . The time, t_1, shall be 0.2 seconds for A, F, TF, O, T aircraft; 0.3 seconds for U, B_I , B_{II} ,C_A aircraft; and 0.4 seconds for C_T aircraft. For the ramp-style control movement, time, t_2, shall be the minimum time that the control is held at the stops to attain the specified load factor.

b. By a longitudinal control movement resulting in a ramp-style displacement time curve as illustrated by the solid straight lines of figure 11(b). The time, t_1, shall be the same as specified in step (a) above. Time, t_3, and the control displacement δ shall be just sufficient to attain the specified load factor in time $2t_1$ plus t_3.

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c. By a longitudinal control movement resulting in a ramp-style displacement curve as illustrated by the solid straight lines of figure 11(c). Time, t_1, shall be the same as specified in step (a) above. Time, t_4, and the control displacement and minus δ/2 shall be just sufficient to attain the specified load factor coincidentally with the attainment of minus δ/2.

Symmetric maneuvers. The airplane shall be at all points on and within the maneuvering envelope of figure 10 unless otherwise specified. Typical symmetric maneuvers are described below.

a. Steady pitching maneuver. The pitching velocity shall be the finite pitching velocity associated with the load factor developed. The longitudinal control is deflected at a very slow rate so that the pitching acceleration is zero.

b. Abrupt pitching maneuver. The airplane initially shall be in steady unaccelerated flight at the airspeed specified for the maneuver and trimmed for zero control forces at that airspeed. The airspeed shall be constant until the specified load factor has been attained. The longitudinal control inputs for these maneuvers are defined in figure 11.

c. Flaps-down pullouts. The airplane shall be at the landing and approach and takeoff limit speed, V_{LF}. The landing gear and other devices that are extended during takeoff or landing approach shall be in their maximum open or maximum extended positions. The load factors shall be all values from 0 to 2.0 for all aircraft except A, F, and TF aircraft. The load factors for these aircraft shall be all values from 0 to 4.0. The steady pitching maneuver and abrupt pitching maneuver conditions described above shall apply.

d. Aerial delivery pullouts. The airplane shall be at the limit speed V_{AD} with the cargo ramp, cargo doors, flaps, etc., in their applicable positions. The load factor shall be all values from 0 to 2.0. The steady pitching maneuver conditions and the abrupt pitching maneuver condition shall apply.

e. Emergency stores release. Emergency release of the most critical combination of required carriage stores shall not result in exceedance of limit strength of the airplane for the following conditions:

(1) At speeds up to the maximum for such release with all values of vertical load factor between 0.5 and 2.0.

(2) At speeds up to V_{LF} with devices in their applicable position for takeoff with all values of vertical load factor between 1.0 and 1.5.

REQUIREMENT LESSONS LEARNED (A.3.4.1.1)

Many modern control systems, particularly fully powered irreversible systems on large aircraft, preclude compliance with precise timing of control movement and peak load factor attainment in abrupt maneuvers such as has been required by previous specifications. In such cases, the intent of the requirement should be met by returning the pitch control to the required position as rapidly as possible without regard to the time of peak load factor occurrence.

Symmetric maneuvers previously specified in MIL-A-008861 were conducted by application of the longitudinal control only. Previous structural design criteria restricts roll maneuvers to 80% of maximum design symmetric load factor (N_Z). Multi-role fighter pilots have indicated the need for roll capability whenever lateral control inputs are commanded. An assessment of the structural capability of the multi-role fighter is underway to determine the roll capability above 80% N_Z. Roll rate commands approaching 50° per second for clean configurations (30° per second with stores) will be used in the assessment.

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Experience has dictated a need for tolerances in flight loads analyses to account for known discrepancies such as air data system errors, attitude errors, system lags, fuel sequence, actuator performance, and rigging. The value selected for each tolerance should be based on results of load sensitivity studies and subject to the approval of the procuring agency. These tolerances shall be applicable until the loads flight test data has validated the maneuver simulation.

A.3.4.1.2 Asymmetric maneuvers.

These maneuvers shall be fully coordinated and, alternately, uncoordinated maneuvers. The analyses shall include tolerances to account for known discrepancies such as air data system errors, attitude errors, control system lags, fuel sequence, actuator performance, and rigging. These tolerances shall be applicable until the loads flight test data has validated the maneuver simulation.

a. Level flight rolls of ___________________.

b. Rolling pull-outs of __________________.

c. Steady pitching maneuvers with abrupt roll (_____) ______________________.

d. Steady rolling maneuvers with abrupt pitch (_____) _______________.

e. Roll rate capability after recovery from an in-flight system failure of 3.2.22 shall not be less than _______.

REQUIREMENT RATIONALE (A.3.4.1.2)

Asymmetric maneuvers represent common operational maneuvers and are a major design load source on primary and secondary structure for all category aircraft. Asymmetric maneuvers for design shall include (but are not limited to) those listed in the requirement guidance section below.

REQUIREMENT GUIDANCE (A.3.4.1.2)

The value of each tolerance used in the analyses shall be specified. Roll capability above 80% maximum symmetric N_Z is required. See guidance specified in 3.4.1.1. Define the rolling maneuver requirements in terms of required parameters, 3.2 and 3.4 and rational combinations thereof. During the maneuver, the cockpit directional control shall be: (1) held fixed at the trim setting required to maintain wings level flight and (2) displaced as necessary to maintain zero sideslip. Level flight rolls and rolling pull-outs of all points on and within the maneuvering envelope bounded by O, A, B, C, D, E, and O of the V-n diagram for symmetrical flight (figure 10) shall be accomplished. For accelerated flight, define the extent of applicability. For roll rate capability after recovery from an in-flight system failure, define the minimum roll rate required to assure continued safe and controlled flight and landing operations.

Rolling maneuvers. The airplane shall be at all points on and within the maneuvering envelope of figure 10 unless otherwise specified. The directional control shall be held fixed in its wings-level trim position with zero rudder control force and displaced as necessary to maintain zero sideslip. The lateral control shall be displaced to the maximum available displacement in not more than 0.1 second for aircraft with stick controls and not more than 0.3 second for airplanes with wheel controls. The maneuver shall be checked in the same manner as entry to the maneuver. Typical rolling maneuvers are described below:

a. Rolling pullout. The initial load factor shall be all values between 0.8 times the symmetric limit load factor and 1.0. The airplane shall be initially in a steady constant altitude turn at an angle of bank to attain the load factor at the specified speed. The

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airplane shall roll out of the turn through an angle of bank equal to twice the initial angle. Constant speed and constant longitudinal control position shall be maintained. The longitudinal control may be moved in proportion to the lateral control motion to prevent resultant load factors in excess of 0.8 times the symmetrical limit load factor.

b. 180° Roll. For A, F, T, and TF aircraft, the load factor shall also be all values from -1.0 to +1.0 with the maneuver starting from level flight and the airplane rolling through 180°.

c. Level flight roll. The initial load factor shall be 1.0. The airplane shall execute a 360° roll starting from level flight. The longitudinal control surface position shall be held constant at the trim position required for level flight prior to commencing the roll.

d. Aerial delivery roll. The speed shall be V_{AD} with the cargo ramp, cargo doors, and flaps in their applicable positions. The load factor shall be 1.0. The lateral control shall be displaced in accordance with item a. above and at the maximum design weight. Roll beyond 60° need not be conducted.

e. Takeoff and landing approach roll. The speed shall be V_{LF} during takeoff and landing approach. The landing gear and other devices that are open or extended during takeoff or landing shall be in their applicable positions. The load factor shall be 1.0. The lateral control shall be displaced in accordance with item a. above. Roll beyond 90° need not be conducted, except that 60° may be used for C and B_{II} aircraft.

REQUIREMENT LESSONS LEARNED (A.3.4.1.2)

Particular care should be exercised to assure rigorous and accurate calculations of roll loads since the outer wing of many aircraft are largely designed by roll requirements. Roll loads on highly swept and flexible wings of high aspect ratio have proven difficult to accurately predict on many past aircraft due to the very large effects of structural deformation on aileron effectiveness and dynamic effects due to abrupt aileron input.

Experience has dictated a need for tolerances in flight loads analyses to account for known discrepancies such as air data system errors, attitude errors, system lags, fuel sequence, actuator performance, and rigging. The value selected for each tolerance should be based on results of load sensitivity studies and subject to the approval of the procuring agency. These tolerances shall be applicable until the loads flight test data has validated the maneuver simulation.

A.3.4.1.3 Directional maneuvers.

The analyses shall include tolerances to account for known discrepancies such as air data system errors, attitude errors, system lags, fuel sequence, actuator performance, and rigging. These tolerances shall be applicable until the loads flight test data has validated the maneuver simulation.

a. Rudder kicks of _______________.

b. Rudder reversals of _______________.

c. Target tracking (____). _______________.

d. Sideslips of _______________.

e. Unsymmetrical thrust with zero sideslip (_____). _____________.

f. Engine failure (____). _______________.

g. Engine-out operation (____). _______________.

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REQUIREMENT RATIONALE (A.3.4.1.3)

Directional maneuvers represent common operational maneuvers and are a major design load source on primary and secondary structure for all category aircraft. Directional maneuvers for design shall include (but are not limited to) those listed in the requirement guidance section below.

REQUIREMENT GUIDANCE (A.3.4.1.3)

The value of each tolerance used in the analyses shall be specified. Define the directional maneuver requirements in terms of required parameters, 3.2 and 3.4 and rational combinations thereof. These maneuvers are essentially flat maneuvers without substantial degree of coupled roll. Longitudinal and lateral control inputs shall be used to maintain the initial load factor and wings level to the greatest extent practical. Both high speed and low speed rudder kicks shall be accomplished at appropriate speeds within the V-n diagram for symmetrical flight. For example, rudder kicks at both low and high speeds shall be accomplished. Low speed rudder kicks shall be performed in the landing configuration(s) at speeds up to V. High speed rudder kicks shall be performed at speeds up to V_L. Rudder reversals shall be accomplished at sufficient speeds to assure safe and controlled flight operations. For example, rudder reversals at speeds up to V_H shall be accomplished by recovery from steady sideslips. Recovery from steady sideslips shall be made at directional control rates up to the maximum limitations of the flight control systems. For ground target tracking, define the extent of applicability. Other sideslip maneuvers such as steady sideslips, unsymmetrical thrust with zero sideslips, engine failures, and engine-out operations shall be accomplished at appropriate speeds within the V-n diagram. For example, sideslips at all speeds up to V_L shall be performed for the steady sideslip maneuvers. Unsymmetrical thrust with zero sideslips shall be performed at the maximum level flight speed attainable with the usable engines and alternately at V_{LF} during landing operations. Engineer failure operations shall be performed at all speeds from the approved one engine-out minimum takeoff speed to V_H. Engine-out operations shall be performed at all speeds from the approved one engine-out minimum takeoff speed to $V_L$for fighters, attack, and trainers and up to V_H for all others.

Directional maneuvers are essentially flat sideslip and yawing maneuvers without substantial degree of coupled roll. The airplane shall be at all points on and within the maneuvering envelope of figure 10 unless otherwise specified. Lateral control displacement shall be included to maintain the wings in a level attitude, except for the high speed rudder kick and reversed rudder conditions described below, an angle of bank shall not exceed 5°. The minimum speeds shall be that speed at which the angle of bank can be maintained. The normal load factor shall be 1.0 for all conditions. Typical directional maneuvers are described below.

a. Steady sideslip. Rudder control force shall be slowly applied until a constant maximum sideslip angle is attained.

b. Low speed rudder kick. The airplane shall be at all speeds up to V_{LF} and for aerial delivery at speeds up to V_{AD} with landing gear and other devices which are open or extended during landing approach or aerial delivery in their applicable positions. The airplane shall be in the configurations defined in 3.2.1 at airspeeds up to 0.6 V_H. The directional control shall be displaced to the maximum available displacement in not more than 0.2 second (0.3 second for C and B_{II} aircraft) and maintained until the maximum overswing sideslip angle is attained and the airplane attains a steady sideslip. Recovery shall be made by reducing the directional control to zero in not more than 0.2 second (0.3 second for C and B_{II} aircraft).

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c. High speed rudder kick. The airplane shall be at speeds up to V_L for A, F, T, and TF aircraft and up to V_H for other aircraft. The directional control shall be displaced to the maximum available displacement in not more than 0.2 second (0.3 second for C and B_{II} aircraft) and maintained until the maximum overswing sideslip angle is attained and the airplane attains a steady sideslip. Recovery shall be made by reducing the directional control to zero in not more than 0.2 second (0.3 second for C and B_{II} aircraft).

d. Reversed rudder (for A, F, T, and TF aircraft only). At speeds up to V_H , recovery from the steady sideslip described in a. above shall be made by application of rudder control force in the opposite direction in not more than 0.2 second.

e. Unsymmetrical thrust with zero sideslip. The most critical engine shall deliver zero thrust or power and shall be in the minimum drag configuration. All other engines shall deliver takeoff thrust or power. The airplane shall be at the maximum level flight speed attainable with the usable engines and alternately at V_{LF} with landing gear and other devices which are open or extended during landing approach in their applicable positions.

f. Engine failure. The airplane shall be at all speeds from approved one-engine-out minimum takeoff speed to V_H. Additionally, at all speeds up to V_{LF} and for aerial delivery at speeds up to V_{AD} with landing gear and other devices which are open or extended during takeoff, landing, or aerial delivery, shall be in their critical positions. The critical engine shall suddenly fail. Thrust decay time histories shall be determined by a rational analysis of the engine characteristics, but in no case shall engine stoppage be considered as occurring in more than 3 seconds. If the engine is equipped with airflow control devices which could produce drag levels in excess of that normally encountered with a wind milling/stopped engine, these higher drag levels must be used in analyses. If reverse thrust is possible because of automatic features, the failed engine shall deliver reverse thrust. All other engines shall deliver normal power or intermediate thrust or power , except for takeoff power or thrust which is applicable at speeds up to V_{LF}. Automatic feathering, decoupling, or thrust-controlling devices shall be operating and alternately not operating. With these devices operating, limit strength is required. Without these devices operating, ultimate strength is required. The directional control shall be held in the neutral position until maximum sideslip is attained and moved in 0.2 second (considering all critical times from the instant of failure to the instant of maximum sideslip) to restore the original heading.

g. Engine-out operations. For multi-engine airplanes, sudden stopping of an engine at all speeds above the approved one-engine-out takeoff speed up to V_L for fighters, attack, and trainers and up to V_H for all others shall not result in unacceptable airplane motions or vibrations. The limit strength of the airplane shall not be exceeded in a symmetrical pullout to a load factor of 2.0 or 1/2 of the load factor specified in 3.2.9, whichever is greater, with one engine at a time inoperative and all other engines delivering normal power or intermediate thrust or power, as applicable.

REQUIREMENT LESSONS LEARNED (A.3.4.1.3)

Previous military requirements specified deflection of the rudder control in 0.2 or 0.3 seconds, depending on aircraft type. Many current aircraft have irreversible position control systems which preclude literal compliance with the time requirement. In such cases, application of the required pilot effort in the specified time has been considered to be satisfactory compliance with the intent of the requirement.

Experience has dictated a need for tolerances in flight loads analyses to account for known discrepancies such as air data system errors, attitude errors, system lags, fuel sequence, actuator performance, and rigging. The value selected for each tolerance should be based on

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results of load sensitivity studies and subject to the approval of the procuring agency. These tolerances shall be applicable until the loads flight test data has validated the maneuver simulation.

A.3.4.1.4 Evasive maneuvers. (____)

The analyses shall include tolerances to account for known discrepancies such as air data system errors, attitude errors, system lags, fuel sequence, actuator performance, and rigging. These tolerances shall be applicable until the loads flight test data has validated the maneuver simulation.

a. Jinking maneuvers of _______________.

b. Missile break maneuvers of _______________.

REQUIREMENT RATIONALE (A.3.4.1.4)

Evasive maneuvers are required during training and combat operations. These maneuvers can generate high service loads on many primary and secondary structural components. Evasive maneuvers for design shall include (but are not limited to) those listed in the requirement guidance section below.

REQUIREMENT GUIDANCE (A.3.4.1.4)

For evasive maneuvers, define the extent of applicability. The value of each tolerance used in the analyses shall be specified. If the subparagraph is applicable, define the evasive maneuver requirements in terms of required parameters, 3.2 and 3.4 and rational combinations thereof. Jinking maneuvers and missile break maneuvers at all speeds up to V_H should be accomplished.

Evasive maneuvers are training and combat maneuvers which are intended to dodge a pursuer, elude enemy ground fire, and break "missile lock." Typical evasive maneuvers are described below:

a. Jinking maneuvers. These maneuvers are initiated by swift movements or sudden turns in order to dodge a pursuer or elude enemy ground fire.

b. Missile break maneuvers. These maneuvers are essentially high load factor turn reversals which are intended to break "missile lock" on the aircraft by abrupt directional changes.

REQUIREMENT LESSONS LEARNED (A.3.4.1.4)

Experience has dictated a need for tolerances in flight loads analyses to account for known discrepancies such as air data system errors, attitude errors, system lags, fuel sequence, actuator performance, and rigging. The value selected for each tolerance should be based on results of load sensitivity studies and subject to the approval of the procuring agency. These tolerances shall be applicable until the loads flight test data has validated the maneuver simulation.

A.3.4.1.5 Other maneuvers. (______)

The analyses shall include tolerances to account for known discrepancies such as air data system errors, attitude errors, system lags, fuel sequence, actuator performance, and rigging. These tolerances shall be applicable until the loads flight test data has validated the maneuver simulation.

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a. Stalls (_____) __________________.

b. Departures (____) __________________.

c. Spins (_____) __________________.

d. Tail slides (___) __________________.

e. __________________.

REQUIREMENT RATIONALE (A.3.4.1.5)

The purpose of this requirement is to establish design loads criteria for primary and secondary structural components during the performance of maneuvers such as stalls and spins.

REQUIREMENT GUIDANCE (A.3.4.1.5)

For other maneuvers, define the extent of applicability. The value of each tolerance used in the analyses shall be specified. Define the maneuver requirements in terms of required parameters, 3.2 and 3.3 and rational combinations thereof. For example, stalls and spins shall be accomplished at all speeds up to V_H.

REQUIREMENT LESSONS LEARNED (A.3.4.1.5)

Stalls. Airplanes which have lifting surfaces so located that they are subject to impingement by the turbulent wake of another stalled lifting surface are subject to significant buffet loads. The horizontal tails of a large and very large transport aircraft experienced design limit loads on the outer two-thirds of their spans as a result of buffet loads during deep stalls. These high loads were measured on the outer span of the horizontal tail when angles of attack exceeding that for maximum wing lift were reached. The T-tail configuration of a large transport places the horizontal tail in relatively clean flow until the airplane is pitched up to an angle where the horizontal tail begins to enter the wing wake. The downwash from the wing keeps the major portion of the wake below the horizontal tail until wing stall occurs. When the wing stalls, the sudden decrease in downwash, coupled with the fact that the angle between the wing and horizontal tail is approximately equal to the stall angle of attack, places the tail directly in the turbulent wake of the wing. Analytical prediction of stall buffet loads has proven to be unsatisfactory unless wind tunnel or full scale test data for similar configurations are available to adjust the results. A wind tunnel investigation was made using a dynamically scaled flutter model to obtain supplemental response data. Use of arbitrary distribution factors, such as the 150-50 distribution results in loads which are too low in the outer span and unnecessarily high at the root. Rational semi-empirical methods are preferred.

Experience has dictated a need for tolerances in flight loads analyses to account for known discrepancies such as air data system errors, attitude errors, system lags, fuel sequence, actuator performance, and rigging. The value selected for each tolerance should be based on results of load sensitivity studies and subject to the approval of the procuring agency. These tolerances shall be applicable until the loads flight test data has validated the maneuver simulation.

A.3.4.1.6 Turbulence.

The airframe shall be capable of operating in the atmosphere with vertical and lateral gusts representative of those expected to be encountered during:

a. (___) Required missions and a gust exceedance rate of _________. The power spectrum of the expected turbulence is defined by _________ and the turbulence field

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parameters are as shown in __________. The airframe shall not have strength less than a level established with limit gust velocity values $Y_d/\ \bar{A}$ of _____________.

b. (___) Wake turbulence _______________.

c. (___) Gust plus maneuver _______________.

d. (___) Other turbulence conditions _______________.

REQUIREMENT RATIONALE (A.3.4.1.6)

Turbulence encounter is a major load source on most transport category aircraft and may cause significant loads on many primary and secondary portions of the structure. The purpose of this requirement is to insure sufficient airframe strength for flight when subjected to atmospheric turbulence, wake turbulence and gust plus maneuvers.

REQUIREMENT GUIDANCE (A.3.4.1.6)

Symmetric and asymmetric gusts are to be considered applicable, particularly for large aircraft and aircraft with T-tails.

The following is applicable regarding the required missions and gust exceedance rates requirement. Gust loads shall be based on the gust environment expected to be encountered while flying the specified mission profiles of 3.2.14.1. Atmospheric turbulence loads shall be established at appropriate speeds within the V-n diagram for symmetrical flight. Large and flexible aircraft must have continuous turbulence requirements made applicable. The continuous turbulence concept uses a power spectral description for atmospheric turbulence and provides for inclusion of the significant rigid body and elastic modes in the analysis to determine response parameters $\bar{A}$ and N_0. These parameters are used in the determination of load magnitudes based on either a specified exceedance rate in the mission profile analysis or at specified gust velocity magnitudes in a flight envelope analysis. NACA Report 1272, NACA Report 1285, SEG-TR-66-45, SEG-TR-67-28, AFFDL-TR-68-55, AFFDL-TR-70-101, AFFDL-TR-68-23, and AGARD Report 586 provide further insight in establishing gust load criteria and describing the atmospheric turbulence. The mission profile analysis approach determines exceedances of gust loads based on specified operational usage. The limit gust load is determined at a specified exceedance rate. Knowledge of expected usage in terms of mission profiles, mission mix, and sortie requirements is essential. This approach can provide for the most consistent strength on a probabilistic basis for airplanes with vastly different operational usage. This approach is also required to determine the repeated gust loads. A frequency of limit load exceedances of 1×10^{-5} cycles per hour or once in ten life times (the lower of the two numbers), may be used in the limit load exceedance rate blank. For the second blank, the power spectrum is defined by the equation:

$$\Phi w(\Omega) = \frac{\sigma_w^2 L}{\pi} \frac{1 + \frac{8}{3}(1.339 L\Omega)^2}{\left[1 + (1.339 L\Omega)^2\right]^{11/6}} \quad \frac{(\mathrm{ft/sec})^2}{\mathrm{rad/ft}}$$

where

Ω is the reduced frequency in radians per foot. The turbulence field parameters to be included in the second blank are shown in table XI. See section 6 for definitions of $\bar{A}$ and N_0. To provide insurance against unconservative definitions of the mission profiles or changes in the mission profiles which would result in flight nearer the limit flight envelope a floor below which the loads cannot drop needs to be established. This is accomplished by providing an airframe

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which can operate within an envelope of reduced severity limit gust velocity values $Y_d / \bar{A}$ as shown below. Recommend the following be included in the third blank.

a. Forty feet per second, EAS from 0 to 1000 feet, then

b. varying linearly to 58 feet per second, EAS at 2500 feet, then

c. varying linearly to 62 feet per second, EAS at 7000 feet, then

d. varying linearly to 55 feet per second, EAS at 27,000 feet, then

e. varying linearly to 14 feet per second, EAS at 80,000 feet.

The envelope of reduced severity limit gust velocity determined loads concept is based on a specified envelope of speed, altitude, gross weight, weight distribution, and center of gravity position and is similar to the discrete limit gust velocity loads determination concept in that both specify gust velocity magnitudes which are applicable to the critical conditions. The resulting gust strength is based on the aircraft's performance capabilities instead of its usage. The mission gust exceedance and envelope of reduced severity limit gust velocities approach provides for the most consistent strength for airplanes with continually varying operational usage.

In the determination of the structural response to continuous turbulence, the time phasing of the induced loads may be an important consideration. The problem is that the gust loads excite the elastic modes of the structure and there is not a simple relation between applied loads and internal loads as in many pilot-induced maneuvers. An example of this type of problem is calculation of wing mounted engine pylon loads. It is easy to see the complex interactions of the six component loads by observing the engine motion under turbulent conditions. Large masses on wing type may behave in a similar fashion. A more subtle example is the bearing and bypass stresses at a wing fastener hole. The phasing used for these loads may significantly affect the crack growth from the fastener hole. The phasing of loads on a structure should be considered and when justified should be included in full scale testing. This applies to strength, durability, and damage tolerance analyses and tests. There are several methods of accounting for load phasing. Among these are a direct PSD analysis for stress at a point, cross power spectral methods, and from time domain analyses. All of these analysis techniques have some shortcomings and the final phasing relationships will have to be derived from flight test measured loads.

Wake turbulence loads shall be established for operational requirements such as aerial refueling, formation flying, and high angle operations at appropriate speeds. Flight conditions which produce maximum airplane response shall be applicable.

Requirements for gust plus maneuver loads shall be identified for aircraft for which operational usage of 3.2.14.1 includes low level terrain following or terrain avoidance operations or low altitude attack missions. The condition can be defined as a discrete 1-cosine gust of specified velocity superimposed on a pilot applied or programmed symmetrical pullup and pushdown. Alternately for the terrain following/avoidance operation, the maneuver plus gust load may be determined at a specified exceedance rate of the maneuver plus gust repeated load occurrences developed under 3.2.14.3. Additional information describing the environmental conditions during low level operations is presented in WADD-TR-60-305, Volume I; ASD-TDR-63-318; AFFDL-TR-64-170; SEG-TR-65-4; and AFFDL-TR-67-13.

The requirements for other turbulence conditions may include consideration of special gust conditions such as for engine out flight or other unusual flight configurations, ground gust effects on control surfaces or large doors, longitudinal gusts or wind shear effects. If the program is a modification program and the airplane gust requirements involve discrete gusts or

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an envelope of gust velocities, then one or both (as applicable) of these requirements may be made applicable in the other turbulence conditions paragraph. Further it may not be necessary to have the full required missions and gust exceedance rate requirements made applicable, if one of the following lesser requirements is adequate; that is, it is known and can be technically supported that the air vehicle/airframe will not be gust critical. Finally, all or some combination of the gust requirements may need to be made applicable to assure and guarantee adequate structural integrity for the airframe encountering gusts, particularly high speed all weather aircraft.

See continuous turbulence requirements guidance (above) regarding definition of turbulence power spectrum.

Regarding discrete gusts, the requirement is to read: discrete gust velocities as shown in (fill in from below). The discrete gust approach does not represent the real turbulence, but provides a model which can be satisfactory over a wide range of aircraft configurations, providing the aircraft exhibits relatively little dynamic response beyond the short period oscillations. Procedures for determining discrete gust load levels essentially neglect the interaction between airplane/power train dynamic responses and the generalized aerodynamic forces. Since the excitation of fundamental structural modes by continuous turbulence is a predominant source of load amplification, the discrete procedures, even with airplane flexibility included, may provide unrealistic results for some airplanes. The discrete gust concept uses a 1-cosine gust shape of given gradient length, to determine aircraft response and airframe loads to specified equivalent gust velocities. When the discrete gust concept is made an applicable requirement, the gust velocities for each altitude shall be:

a. 66 feet per second (EAS) from 0 to 20,000 feet at V_G.

b. 50 feet per second (EAS) from 0 to 20,000 feet at V_H.

c. 25 feet per second (EAS) from 0 to 20,000 feet at V_L.

d. From 20,000 to 50,000 feet, reduce the limit gust velocities linearly from 66 feet per second (EAS) to 38 feet per second (EAS), 50 feet per second (EAS) to 25 feet per second (EAS), and 25 feet per second (EAS) to 12.5 feet per second (EAS).

e. For altitudes above 50,000 feet, multiply the design gust velocities by $\sqrt{\sigma \text{altitude}} / \sqrt{\sigma 50{,}000}$

where $\sigma = \rho / \rho_0$.

REQUIREMENT LESSONS LEARNED (A.3.4.1.6)

The criticality of loading conditions associated with turbulence is dependent on both the airplane's intended use and its external configuration. Analytical procedures to be specified for determining gust loads therefore must recognize these considerations. A discrete gust requirement may be appropriate for an airplane which must possess high maneuvering capability, whereas a supplemental continuous turbulence analysis may also be desirable for airplanes for which gust loads are anticipated to be a significant structural factor. Historically, discrete gust requirements have provided adequate load levels; however, the more extensive power spectral continuous turbulence procedures provide for the assessment of advanced technology configurations which may incorporate such features as lighter weight high-aspect-ratio wings, active automatic load redistribution devices, and stability augmentation systems. Four contemporary transport category aircraft ranging in gross weights from 20,000 pounds to 750,000 pounds were evaluated in AFFDL-TR-67-13 with the abbreviated power spectra technique of AFFDL-TR-73-118 and AFFDL-TR-70-106 and found to have safe load levels.

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The expected gust loads for each of these aircraft had been determined by various forms of discrete gust criteria; therefore, the use of supplemental continuous turbulence analyses for the determination of gust encounter loads would not have provided any additional strength benefits.

In general, discrete gust loads tend to be more critical for aircraft with low wing loadings, whereas continuous turbulence loads tend to be critical for high wing loadings. The use of power spectral techniques to assess the strength capability of airplanes subjected to continuous turbulence has been found to be the most rational approach to the airplane gust problem. There are two general problems with a detailed gust power spectral analysis. The first is that the power spectral techniques are based on the assumption of linearity. The second is in the interpretation of the statistical results in terms that are meaningful to the design and test engineer. Limit on control surface deflection and rates capabilities, introduce nonlinearities which cannot be handled directly by the power spectral analyses techniques. Separate nonlinear analyses must be performed to determine these effects and the PSD results must be compensated. The loads such as shear, bending moment, and torsion at various points on the structure resulting from the analysis are defined statistically and are not identified in the time domain so the phasing is undefined. It is necessary to generate design conditions that match in realistic combinations the statistically defined loads. Various approaches to the development of design conditions have been proposed. FAA-ADS-53 and FAA-ADS-54 provide a concept for the determination of a design condition from unshared statistical loads, as well as considerations to account for non-linearities in the determination of statistical loads from the PSD analyses. The PSD techniques are described in AFFDL-TR-67-74, AFFDL-TR-69-11, NACA Report 1172, and AFFDL-TR-66-35.

For the mission profile analysis, ultimate gust loads should not be based on a probability of exceedance of ultimate load. The resulting extremely large loads raise legitimate questions whether these are representative of continuous turbulence and whether the aerodynamic and structural characteristics can be modeled realistically when approaching ultimate load. For a swing wing bomber, the mission profile limit gust loads or stresses at a critical point were established at a frequency of exceedance of 2×10^{-5} exceedances per hour. The loads at this exceedance rate were determined from an exceedance curve which includes the summation of exceedances over all mission segments. The specified exceedance rate applied equally to positive and negative loads and is identical for both the vertical and lateral components of the turbulence.

Wake turbulence loads are those which are induced on the aircraft, or a component thereof, by the turbulent nature of airflow separation from either another aircraft or from a portion of the aircraft itself. This latter consideration is dependent on the aircraft's geometric features and it includes the effects of conventional arrangements of the wing, empennage, nacelles, and external stores; it also includes the effects of unconventional protrusions such as special antennae, large radomes, and rotodomes. These effects are generally established by either wind tunnel test on a dynamic model or by empirical comparisons for similar designs. Verification is made by flight testing.

The influence of the wake from another aircraft is dependent on both the relative size of the aircraft involved and their proximity to each other. Intentional close proximity operations such as formation flying and aerial refueling result in loads being generated either directly from the turbulent wake, indirectly from the control inputs required to maintain the attitudes necessary during the operations or a combination of both. Analytical procedures must include both rigid body and flexible modes and the interaction with any automatic load redistribution devices or controls, such as a stability augmentation system. Data sources may be analytical, empirical, or comparative.

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Wing tip mounted missiles were lost from an air superiority fighter on two occasions when jet wakes were encountered. The causes were identified as high wing tip accelerations in combination with substandard cast fittings used to attach the launchers to the wing tips. The wake phenomena was investigated by the British as reported in A.R.C. Technical Report C.P. No. 282. A method for assessing the impact of wake vortices on USAF operations is provided in AFFDL-TR-3060.

A.3.4.1.7 Aerial refueling. (_____).

A.3.4.1.7.1 Tanker. (____)

The flight loading condition requirements for tanker air vehicles during refueling are ______________________.

A.3.4.1.7.2 Receiver. (____)

The flight loading condition requirements for receiver air vehicles during refueling are _______________.

REQUIREMENT RATIONALE (A.3.4.1.7)

The purpose of this requirement is to establish structural requirements for tanker and receiver air vehicles during aerial refueling operations.

REQUIREMENT GUIDANCE (A.3.4.1.7

For aerial refueling, define the extent of applicability. If the subparagraph is applicable, define the refueling requirements in terms of required parameters 3.2 and 3.3, and rational combinations thereof. For example, the flight loading condition requirements for tanker and receiver air vehicles during refueling are in terms of flight loading conditions which apply to the mounting and carry-through structures for the probe and boom receptacle aerial refueling systems. The probe-drogue and flying boom types of aerial refueling systems shall comply with appropriate specifications. The aerial refueling drogue shall be capable of withstanding impact loads produced by the receiver's probe at an angular drogue position of 15 degrees off center and at velocities up to 10 feet per second. The load on the probe-mast shall be those resulting from encountering a 30 foot per second gust up to an altitude of 20,000 feet. For altitudes above 20,000 feet, the gust velocity may be reduced linearly from 30 feet per second to 15 feet per second at 50,000 feet. The gust shall be considered to act at all positions from 0 degrees to 360 degrees in a direction normal to the flight path. The probe, nozzle, and aircraft attachment structure shall be able to withstand the following limit loads at contact, within the specified fuel transfer envelope and at disconnect throughout the aerial refueling envelope:

a. A 1000 pound compression load with a 3000 pound radial load.

b. A 1000 pound tensile load in combination with a 3000 pound radial load.

c. A 2000 pound tensile load and a 2000 pound compression load.

Operating loads at normal refueling positions within the specified fuel transfer envelope should be maintained within 2/3 of limit load to minimize impact on fatigue life.

The tensile loads shall be applied at the latching shoulder parallel to the axis of the nozzle. The radial loads shall be applied to the nozzle sleeve 3.5 inches from the gage point in the toggle latching groove. The compression load shall be applied at the lip of the nozzle sleeve and parallel to the longitudinal axis of the nozzle. A hose load of 2,770 pounds shall be applied in a 160 degree cone about the normal trail axis.

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In addition to air loads and other loads normally imposed on the aircraft structure, the slipway and its door shall be capable of withstanding impact loads imposed by contact with the boom nozzle. The slipway door shall be capable of withstanding ultimate loads of 2,000 pounds laterally and 5,000 pounds vertically. In addition to normal aerodynamic and inertia loads, the aircraft skin backup structure surrounding the receptacle/slipway shall be capable of withstanding impact loads imposed by inadvertent contact with the boom nozzle. The skin area out to 12 inches from the perimeter of the receptacle face slipway installation shall be capable of withstanding ultimate loads of 750 pounds laterally and 1800 pounds vertically.

The boom receptacle shall be able to withstand the following loads at contact, within the specified fuel transfer envelope and at disconnect throughout the aerial refueling envelope:

a. Tension - An ultimate load of 14,000/(Cos A) pounds applied to the boom-nozzle ball joint, where the angle A may vary from 0 degrees to 30 degrees.

b. Compression - An ultimate load of 20,000 pounds applied at the boom-nozzle ball joint anywhere within a 34 degree cone.

c. Tension and compression working load - A limit load of 9,000/(Cos C) pounds applied at the boom-nozzle ball joint where angle C may vary from 0 degrees to 17 degrees.

Angles A and C are taken relative to the receptacle axis. Fuel flow pressure shall be added to the above loads only when the resulting incremental load is additive. In both cases, use of ailerons to maintain wing level is a major source of load and the abruptness and amount of aileron used is highly pilot dependent.

Review and include as applicable the Standardization Agreement 3447ASP on in-flight (aerial) refueling equipment, dimensional and functional characteristics.

REQUIREMENT LESSONS LEARNED (A.3.4.1.7)

Loads incurred by the receiver aircraft during aerial refueling have been shown during testing of a large transport and very large transport to be more dependent upon the pilot than the aircraft characteristics. The sensitivity of the aircraft to the loads encountered is dependent primarily upon the structural characteristics of the aircraft. Cargo aircraft with low design stress levels in the outer wing proved insensitive to the aerial refueling loads, while the fatigue life of a larger cargo aircraft was noticeably affected.

Vibration failures occurred in an electronics aircraft empennage (receiver) during aerial refueling behind a large tanker/transport, see AFWAL/FIBG 81-2.

A.3.4.1.8 Aerial delivery. (___)

The aerial delivery flight loading conditions are ________________.

REQUIREMENT RATIONALE (A.3.4.1.8)

The purpose of this requirement is to establish structural requirements for air vehicles operating in the aerial delivery configuration during airdrop, jettison, and air transport. Airdrop and jettison typically cause limit loads on the ramp doors, cargo doors, and structure directly associated with the aerial delivery modes.

REQUIREMENT GUIDANCE (A.3.4.1.8)

For aerial delivery, define the aerial delivery requirements in terms of required parameters 3.2 and 3.3 and rational combinations thereof. Aerial delivery structural requirements shall be established for operational requirements such as air transport and airdrop operations at appropriate speeds. For example, the aerial delivery flight loading conditions are in terms of

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loading conditions which result from flight and ground operations and crash conditions. All attachments and support structure shall be capable of supporting and restraining air transport cargo, airdrop cargo, airdrop subsystems, and the aerial delivery systems during all required and expected service usage. Aerial delivery capability shall be established at speeds up to V_L and at speeds specified for airdrop operations.

Airdrop and jettison criteria have typically involved the assumption of 1.0g flight with the aircraft trimmed to approximately a two degree nose-up deck angle. An extraction acceleration requirement of 0.25g has been used for jettison. A 1-Cosine, 25 fps discrete gust has been superimposed on other airdrop conditions so as to cause peak airframe response during the time the cargo package is on the ramp lip. While loads on primary structure are normally less in the aerial delivery configuration than in other configurations, maximum stress levels may occur in the aft fuselage if the cargo door or ramp carry a significant portion of the aft fuselage load when closed.

Provisions for storage and ejection of the extraction or drogue parachutes are the subject of international standardization agreement STANAG 3469TN on parachute extraction assemblies and aircraft extraction parachute ejector installations. When these provisions affect or violate the international agreement concerned, the preparing activity will take appropriate reconciliation action through international channels including departmental standardization offices, as required. The paratroop door deflector, jump platform, and cargo ramp/door must be capable of being deployed at the designated airdrop speeds. The paratroop anchor line cable must be capable of withstanding one towed paratrooper and the designated number of towed deployment bags at the maximum speed for personnel airdrop. For a 300-pound paratrooper at 130 KIAS, a 3500-pound shock load can be applied to the anchor line cable at the most severe load inducement angle. The Air Delivery System (ADS) anchor line cable, which may be separate from the paratroop anchor line cables, must be capable of withstanding the total number of towed deployment bags for the maximum speed for cargo airdrop. At 150 KCAS, a 3,500 pound shock load can be applied to the ADS anchor line cable perpendicular to the aircraft centerline.

For platform airdrop, the cargo handling system is normally capable of withstanding 1.5 g extractions for low velocity platform airdrop, and 3.0 g for LAPES. The cargo handling airdrop aft restraint is normally capable of withstanding 0.5 of the maximum parachute force at that airspeed prior to release and extraction. Based upon trade studies, all airframe aerial delivery alternate mission kit interfaces, each capable of withstanding the loads from the applicable kit, must be identified.

REQUIREMENT LESSONS LEARNED (A.3.4.1.8)

An unusual load problem was observed on a cargo aircraft with large petal doors which open just wide enough to permit passage of the cargo. When packages of large cross sectional area are dropped at high extraction rates a negative pressure increment is created inside the cargo compartment. As the cargo package passes the petal doors an inward acting impulse load is created. The impulse load can be successfully predicted by rational analysis and can be an important consideration for some door configurations. Aircraft paratroop door deflectors, jump platforms, and cargo ramp/door deployments are for some air vehicles limited to 150 KIAS (transport), 200 KCAS (large transport), and 205 KCAS or M = .45 whichever is more restrictive (very large transport). A limited number of transport aircraft have modified cargo ramps capable of being deployed at 250 KIAS. Due to the relatively high velocity of the cargo package during extraction, the coreolis effect term is significant in providing load relief for the cargo ramp and should be included in the rational analysis of airplane response to define design ramp

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loads. Due to the lesser coreolis effect, maximum ramp loads are most likely to occur during jettison.

A.3.4.1.9 Speed and lift control. (____).

A.3.4.1.9.1. Speed control. (____)

The flight loading conditions for speed controlling devices are ____________.

A.3.4.1.9.2. Lift control. (_____)

The flight loading conditions for lift controlling devices are ____________.

REQUIREMENT RATIONALE (A.3.4.1.9 through 3.4.1.9.2)

The purpose of this requirement is to define structural requirements for the speed and lift control devices including their effects on other structure.

REQUIREMENT GUIDANCE (A.3.4.1.9 through 3.4.1.9.2)

For speed and lift control, define the extent of applicability. If the subparagraph is applicable, define the speed and lift control requirements in terms of required parameters 3.2 and rational combinations thereof. For example, the flight loading conditions for speed and lift controlling devices are in terms of loading conditions which are applicable to the speed and lift control devices and all other structure affected by these devices. Speed and lift control loads shall be established at speeds up to those specified in 3.2.7.3.

REQUIREMENT LESSONS LEARNED (A.3.4.1.9 through 3.4.1.9.2)

A wide variety of speed and lift control devices have been used in the past, including in-flight reverse thrusters, spoilers, flaps, speed brakes, automatic lift distribution control (ailerons or spoilers) and modal suppression systems. Most problems encountered with such systems have been associated with buffet, trim changes, and inadvertent deployment or gapping at speeds higher than intended for use. With the exception of the buffet load increments, the loads are predictable by rational analysis. Prediction of buffet loads requires wind tunnel or full scale test results, preferably the latter. Additional information on buffet loads is presented in AFFDL-TR-72-46.

A.3.4.1.10 Braking wheels in air. (______)

________________.

REQUIREMENT RATIONALE (A.3.4.1.10)

The purpose of this requirement is to define structural requirements for landing gear systems equipped with brakes. Application of braking torque can produce high load levels on the support and back-up structure.

REQUIREMENT GUIDANCE (A.3.4.1.10)

For braking wheels in air, define the braking requirements in terms of required parameters 3.2 and 3.3, and rational combinations thereof. For example, the airplane shall be airborne in the takeoff configuration with the landing gear in any position between fully extended and fully retracted. All wheels equipped with brakes shall be brought to rest by application of braking torque. The airspeed and wheel peripheral speed shall be 1.3 times the stalling speed in the

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takeoff configuration. The maximum static braking torque shall be applied from zero to the maximum static value in 0.2 seconds.

REQUIREMENT LESSONS LEARNED (A.3.4.1.10)

A.3.4.1.11 Extension and retraction of landing gear. (_____)

__________________.

REQUIREMENT RATIONALE (A.3.4.1.11)

The purpose of this requirement is to define structural requirements for extension and retraction of landing gear systems. Extension and retraction of landing gears can produce high load levels on the support and back-up structure.

REQUIREMENT GUIDANCE (A.3.4.1.11)

For extension and retraction of landing gear, define the landing gear extension and retraction requirements in terms of required parameters 3.2 and 3.3, and rational combinations thereof. For example, the following loadings shall act separately and simultaneously with the landing gear in each critical position between fully extended and fully retracted:

a. Aerodynamic loads up to the limit speed specified for the takeoff and landing configuration.

b. Inertia loads corresponding to the maximum and minimum symmetrical limit load factors specified for flight in the takeoff and landing configurations.

c. Inertia loads resulting from accelerations of those parts of the landing gear that move relative to the airplane during extension or retraction. The accelerations shall be those resulting from use of maximum available power of the extension and retraction system.

d. Gyroscopic loads resulting from wheels rotating at peripheral speed equal to 1.3 times the stalling speed in the takeoff configuration and retracting or extending at the maximum rates attainable.

REQUIREMENT LESSONS LEARNED (A.3.4.1.11)

A.3.4.1.12 Pressurization.

The pressure differentials to be used in the design of pressurized portions of the airframe, including fuel tanks, shall be the maximum pressure differentials attainable during flight within the design flight envelope, during ground maintenance, and during ground storage or transportation of the air vehicle. These maximum pressure differentials shall be the maximum attainable with the normal operation of the pressure regulation system nominal settings plus manufacturing tolerance or the maximum pressure differentials attainable during or following the system failures of 3.2.22 which occur at a rate greater than or equal to that specified in 3.2.11. These maximum pressure differentials shall include both positive, inside-to-outside, and negative, outside-to-inside pressure differentials as well as pressure differentials across pressure boundaries separating adjacent internal compartments. Where appropriate, these pressures shall be combined with other flight loads to obtain the most critical combination of flight and pressurization loads. The internal stresses and strains arising from the pressurization loads shall not be assumed to be relieving from other flight loads unless the probability of a loss of pressurization is less than the rate specified in 3.2.11. Similarly, structural stabilization derived from pressurization shall not be used to achieve required structural performance

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capabilities unless the probability of the loss of pressurization is less than the rate specified in 3.2.11.

a. For normal flight operations, the maximum pressure differentials attainable shall be increased by a factor not less than _______________ when acting separately or in combination with 1g level flight loads. These maximum pressure differentials shall include the effects of undetectable or uncontrollable system failures of 3.2.22.

b. For emergency flight operations or when combined with maximum maneuver flight loads, the maximum pressure differentials attainable shall be increased by a factor not less than _______________. These maximum pressure differentials shall include the effects of detectable and controllable system failures of 3.2.22.

c. For ground operations including maintenance, the maximum pressure differentials attainable shall be increased by a factor not less than ______________. These maximum pressure differentials shall include the effects of the system failures of 3.2.22 occurring during maintenance, storage, fueling, and ground transportation of the air vehicle.

REQUIREMENT RATIONALE (A.3.4.1.12)

This requirement defines the methods to be used in determining the pressure differentials to be used in the design of the airframe.

REQUIREMENT GUIDANCE (A.3.4.1.12)

In subparagraphs a and c, the recommended factor is 1.33. This value is typically greater than 1.00 to provide a static strength margin above the pressurization loads normally encountered during flight and ground operations. A value larger than 1.33 should be used where the uncertainties in the predictive methods and the correct functioning of the pressure control system are greater than normal. A value less than 1.33 is not recommended.

In subparagraph b, the recommended factor is 1.00. This value should be increased where the uncertainties in the predictive methods and the correct functioning of the pressure control system in emergency circumstances are greater than normal. A value less than 1.00 is not recommended.

Special consideration should be given to the selection of the pressurization design requirements for cryogenic fuel tanks. Such tanks may require elaborate temperature and pressure control systems. The correct functioning of these systems during sudden maneuvers or emergency conditions may be difficult to predict accurately.

It is also necessary to define negative pressure differential requirements. Negative pressure differentials may develop during rapid changes in altitude or with failures in the pressure control system. Negative pressure differentials may also occur during maintenance and ground storage. In cryogenically fueled vehicles, rapid internal temperature and pressure changes, associated with fuel loading and fuel sloshing, may develop high negative pressure differentials.

REQUIREMENT LESSONS LEARNED (A.3.4.1.12)

It is alleged that certain earlier commercial aircraft have burst/ruptured in flight due to lack of pressure factors. Ultimate pressures acting alone, can produce the most severe loading condition on certain fuselages, especially those having large, noncircular type cross sections. Static pressurization tests have produced rupture failures, thus supporting the necessity of requiring pressure factors. Pneumatic testing of a system is hazardous and failure can cause extensive system damage and injury to personnel nearby. Therefore, submerged, hydrostatic testing with fluids has been developed and used for fuselages and other pressure vessels.

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MIL-A-008861, as well as predecessor specifications MIL-S-5705 and USAF Specification No. R-1803-5, previously called out these same, limit pressure factors.

A.3.4.1.13 Aeroelastic deformation effects. (____)

Aeroelastic deformations shall be included when determining the final airload distributions.

REQUIREMENT RATIONALE (A.3.4.1.13)

The purpose of this requirement is to define the aeroelastic deformation effects associated with aircraft structural deflections. Significant changes in aircraft airload distributions and stability may occur as a result of these deflections.

REQUIREMENT GUIDANCE (A.3.4.1.13)

For aeroelastic deformation effects, define the requirement in terms of required parameters 3.2 and 3.3, and rational combinations thereof. For example, aeroelastic deformation effects shall be included in the determination of the final airload distributions. Aeroelastic deformation effects shall be determined by a steady state aeroelastic analysis which includes the mutual interaction between aerodynamic, inertial, and structural elastic forces.

REQUIREMENT LESSONS LEARNED (A.3.4.1.13)

Aeroelastic deformation effects proved to be very significant in designing a forward swept wing demonstrator aircraft, an early SST, and highly flexible aircraft (such as bombers, transports, and gliders).

A.3.4.1.14 Dynamic response during flight operations. (_____)

The dynamic response of the air vehicle resulting from the transient or sudden application of loads shall be included in the determination of design loads.

REQUIREMENT RATIONALE (A.3.4.1.14)

The purpose of this requirement is to establish the maximum loads resulting from dynamic response of the air vehicle during flight operations.

REQUIREMENT GUIDANCE (A.3.4.1.14)

For dynamic response during flight operations, define the requirement in terms of required parameters 3.2 and 3.3, and rational combinations thereof. Structural requirements shall be established for flight operations which produce dynamic response of the air vehicle as a result of transient or sudden application of loads resulting from sources such as abrupt maneuvers, release or ejection of stores, aerial delivery of cargo, and nuclear blasts. Maximum loads resulting from these conditions shall be determined by dynamic analyses and combined with steady state loads to establish the structural design loads.

REQUIREMENT LESSONS LEARNED (A.3.4.1.14)

The vertical tail of an electronic countermeasures aircraft was redesigned to account for the high dynamic loads encountered during structural flight testing. High lateral accelerations were measured during subsonic stick jab maneuvers. A 20g inertia loading condition was chosen for structural evaluation. This condition also represented 66 fps gust encounter loads at supersonic speeds.

Impinging shock waves from separating empty wing fuel tanks off a multti-role fighter resulted in fuel tank jettison restrictions for certain loading configurations. The high dynamic loads from

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simultaneous supersonic tank jettison resulted in the restriction of simultaneous wing tank jettison to subsonic speeds.

A.3.4.1.15 Other flight loading conditions. (____)

____________________.

REQUIREMENT RATIONALE (A.3.4.1.15)

The purpose of this requirement is to establish structural requirements for other flight loading conditions which may exist.

REQUIREMENT GUIDANCE (A.3.4.1.15)

For other flight loading conditions, define the other flight requirements. For example, with the landing gear fully extended and not in contact with the ground, a rebound load factor of -20.0 shall act on the unsprung weight of the landing gear along the line of motion of the strut as it approached the fully extended position. Other flight loading conditions may need to be defined such as engine stalls, weapon carriage and release, and windshield bird proofing. AFFDL-TR-73-103 provides information for establishing structural requirements for bird strikes. Other flight loading conditions shall include consideration of system failures (3.2.22).

REQUIREMENT LESSONS LEARNED (A.3.4.1.15)

A.4.4.1 Flight loading conditions.

Analyses and tests shall be of sufficient scope to determine and verify the loads resulting from and commensurate with the flight loading conditions of 3.4.1.

VERIFICATION RATIONALE (A.4.4.1)

This verification task is required to assure that the flight loading conditions are appropriately determined and formally established to assure that the airframe has adequate structural integrity for its required service usage.

VERIFICATION GUIDANCE (A.4.4.1)

Aircraft flight loads and dynamic response analyses and tests shall be conducted to determine the adequacy of the design loads analyses and verify the structural integrity of the aircraft. The flight and dynamic response tests shall be sufficient in scope to assure that all critical design loads are established. These tests shall consist of measuring static and dynamic loads on an instrumented and calibrated test aircraft for flight loading conditions such as those associated with pilot induced maneuvers, loss of control maneuvers, release or ejection of stores, aerial delivery of cargo, and turbulence. Further guidance on aircraft flight tests can be found in the Verification Guidance of 4.4.

VERIFICATION LESSONS LEARNED (A.4.4.1)

Flight test simulation of steady maneuvers is often complicated by the introduction of unintended dynamic effects. Particular emphasis should be placed on slow entry and recovery when demonstrating steady maneuvers.

Extra care is needed in planning and in executing flight testing in several areas, which include:

a. Trim requirements - especially for those cases where a dive is required to attain the test speed.

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b. High speed/high Mach number symmetrical maneuvers may require pilot input of roll control devices in order to maintain a wing's level flight condition. When comparing the resultant measured loads with analytical loads, the effect of the roll control devices must be accounted for.

High g/Mach conditions may be difficult to attain on some aircraft. For such cases, attainment of the Mach point should be given top priority, since load factor variations can be easily corrected by analytical means, while Mach correction cannot.

A.3.4.2 Ground loading conditions.

Ground loading conditions are generally not truly realistic conditions but situations which should result in design loads. These conditions shall consider both required and expected to be encountered critical combinations of configurations, gross weights, centers of gravity, landing gear/tire servicing, external environments, thrust or power, and speeds and shall be used in the design of the airframe. Ground operations shall include symmetric and unsymmetric fuel and payload loadings and adverse trim conditions. The following conditions reflect required ground operations and maintenance capability of the air vehicle. Forcing functions and time histories for shipboard carrier catapult and arresting gear are provided in MIL-STD-2066. Barricade deceleration is as shown in NAEC-MISC-06900. The structural integrity of the airframe shall be adequate for the air vehicle to perform as required.

REQUIREMENT RATIONALE (A.3.4.2)

The purpose of this requirement is to insure that all applicable ground loading conditions are established in accordance with the detailed structural criteria of 3.1.1.

REQUIREMENT GUIDANCE (A.3.4.2)

Ground loading conditions are defined by establishing conditions which reflect ground and maintenance operations. These conditions include landing, ground operations, and ground handling or maintenance. Ground operations consists of taxiing, turning, pivoting, braking, and takeoff. Ground handling consists of towing, jacking, and hoisting. Limit loads for the landing operations are obtained by investigating various aircraft attitudes at ground contact in conjunction with the air vehicle flying at the specified landing and sinking speeds. A typical set of landing conditions for an aircraft with tricycle gear is as follows:

a. Level landing, three point

b. Level landing, two point

c. Tail down landing

d. One wheel landing

e. Drift landing

Gear reactions and aircraft accelerations are determined for each condition. The loads on the landing gear are externally applied forces and are placed in equilibrium by translational and rotational inertia forces of the air vehicle. In addition to the static loads on the landing gear, loads associated with accelerating the wheel assembly up to the landing speed must be considered. These spin-up loads are difficult to determine rationally and equally difficult to measure in tower drop test. ANC-2 provides semi-empirical equations for calculating the spin-up loads (drag loads) and vertical loads at the time of peak spin-up loads.

The elasticity of the landing gear assembly is to be considered in determining the forward acting loads. It is assumed that following the wheel spin-up, when the sliding friction has

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reduced to zero, the energy stored in the gear as a result of rearward deformation causes the wheel mass to spring forward resulting in a sizable forward inertia load. This forward acting dynamic springback load is considered to occur about the time the vertical load reaches its maximum. ANC-2 provides a method of analysis for springback loads along with the spin-up load analysis mentioned previously.

Generally, the spin-up and springback loads can be assumed as high frequency loadings, to which the total aircraft mass does not respond. However, some components of the air vehicle can respond, for example external stores, engines on wing-pylons, etc.

The landing gear loads associated with ground operations are also defined in ANC-2. For a tricycle gear these conditions are as follows:

a. Braked roll - three wheels

b. Braked roll - two wheels

c. Unsymmetrical braking

d. Reverse braking

e. Turning

f. Pivoting

In all braked roll conditions, the air vehicle should be in a horizontal attitude. The friction coefficient of the braked wheels is 0.8. For the turning condition, the air vehicle is considered in a three point attitude while executing a turn. The ratio of side load to vertical load is considered to be the same on each gear. The lateral load factor is 0.5 or that lesser value which causes overturning. For the pivoting condition, the brakes are locked on one wheel unit and the air vehicle is pivoted about that unit. A coefficient of friction of 0.8 is assumed in the analysis.

Runway roughness for ground operations will be stated in terms of power spectral density levels or discrete bumps and dips.

REQUIREMENT LESSONS LEARNED (A.3.4.2)

The ground loading conditions should be carefully established since these conditions are used to determine the service loads and ground loads which the airframe must sustain during its expected usage. In general, ground loading conditions are not truly realistic conditions but are situations that should result in loads which equal or exceed those expected from realistic conditions. Ground loading conditions such as landing and ground handling were previously specified in MIL-A-008862. Catapult and arrestment condition requirements were defined by MIL-A-008863. Requirements for crash and ditching conditions, control system conditions, refueling conditions, and other miscellaneous conditions were defined by MIL-A-008865.

A.3.4.2.1 Taxi.

a. Dynamic taxi conditions. __________________.

b. 2.0g Taxi. (____) Taxi conditions at all critical combinations of ___________________.

REQUIREMENT RATIONALE (A.3.4.2.1)

The purpose of this requirement is to establish structural requirements for straight ahead taxi without braking. Straight taxi typically produces maximum vertical loads on the landing gear and may produce significant loadings on other primary structure.

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REQUIREMENT GUIDANCE (A.3.4.2.1)

Define the taxi requirements in terms of required parameters 3.2 and 3.3, and rational combinations thereof. Dynamic taxi conditions should be based on operational requirements such as taxiway, runway, and tire conditions. Taxi loads shall be established at appropriate speeds in accordance with 3.2.7. For example, low speed taxi on taxiways and ramps of paved and semiprepared airfields at speeds up to the taxi limit speed, V_T and high speed taxi on runways of paved and semiprepared airfields at speeds up to the lift-off limit speed, V_{LO}. The appropriate effects of weight, cg position, mass distribution, and landing gear characteristics will be included. RTD-TDR-63-4139 Vol. I and ASD-TDR-62-555 Vol. I provide criteria and analysis techniques for establishing alighting gear dynamic loads. Further guidance on dynamic taxi loads is presented in 3.4.2.7. Alternately, with approval of the procuring agency, a 2.0g taxi analysis may be substituted. If applicable, define the extent of applicability. For example, taxi conditions at all critical combinations of aircraft weight, c.g., and mass distributions shall be included in the analyses. The sum of the vertical loads acting at the ground shall be 2.0W where W is the weight of the aircraft. The total load of 2.0W shall be reacted at each mass item. For nose gear design, 3.0W shall be used instead of 2.0W. No wing lift shall be considered for the 2.0g taxi condition. To account for taxi asymmetry and servicing, loads should be distributed equally (50/50) and alternately 60/40.

REQUIREMENT LESSONS LEARNED (A.3.4.2.1)

A.3.4.2.2 Turns.

a. Turns on ramps at speeds up to ________________.

b. Turns on taxiways at speeds up to ________________.

c. Runway turn-offs at speeds up to ________________.

REQUIREMENT RATIONALE (A.3.4.2.2)

The purpose of this requirement is to provide structural requirements for unbraked steady turns.

REQUIREMENT GUIDANCE (A.3.4.2.2)

Define the turn requirements in terms of required parameters of 3.2 and 3.3, and rational combinations thereof. Turning design loads should be based on operational requirements such as taxiway, runway, and tire conditions. Turning requirements shall be established at appropriate speeds of 3.2.7, but nose gear steering angle and associated turn speed need not exceed those required for a lateral load factor of 0.5g at the aircraft center of gravity. For example, turns on ramps at speeds up to the taxi limit speed, V_T on paved and semiprepared surfaces. Turns on taxiways at speeds up to the taxi limit speeds, V_T on paved and semiprepared surfaces. Runway turn-offs at speeds up to the taxi limit speed, V_T, on paved and semiprepared surfaces. The effects of weight, cg position, mass distribution, and landing gear characteristics shall be accounted for.

REQUIREMENT LESSONS LEARNED (A.3.4.2.2)

A technique for establishing lateral load factors during ground turning is presented in ASD-TR-79-5037.

A.3.4.2.3 Pivots. (____)

a. The pivot points are ________________.

b. The power or thrust levels shall be ________________.

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REQUIREMENT RATIONALE (A.3.4.2.3)

The purpose of this requirement is to establish maximum torsional load on the main landing gear.

REQUIREMENT GUIDANCE (A.3.4.2.3)

For each applicable subparagraph define the pivoting requirements in terms of the required parameters of 3.2 and 3.3, and rational combination thereof. For example, the pivot points are about one main landing gear wheel with brakes locked, or in the case of multiple wheel gear units, about the centroid of contact area of all wheels in the gear units. The power and thrust levels should be based on a rational analysis to determine power required to perform the maneuver. The coefficient of friction between the tires and ground shall be 0.8 and the vertical load factor at the c.g. shall be 1.0. Some aircraft configurations, such as a very large transport, preclude true pivot turns, in which cases a minimum radius turn should be defined in 3.4.2.2 instead of pivoting.

REQUIREMENT LESSONS LEARNED (A.3.4.2.3)

Use of a 0.8 coefficient of friction has proven to yield satisfactory loads.

A.3.4.2.4 Braking

a. Braking during taxi on ________________.

b. Braking during turns on ________________.

c. Pivoting. (____) Braking during pivoting of ________________.

d. Braking after an aborted takeoff on ________________.

e. Braking after landing of ________________.

REQUIREMENT RATIONALE (A.3.4.2.4)

The purpose of this requirement is to establish structural requirements for ground handling involving the use of braking.

REQUIREMENT GUIDANCE (A.3.4.2.4)

Define the braking requirements in terms of required parameters of 3.2 and 3.3, and rational combination thereof. Braking design loads should be based on operational requirements such as taxiway, runway, and tire conditions. Braking requirements shall be established at appropriate speeds of 3.2.7. For example, taxiing and turning on paved and semiprepared surfaces, at speeds up to the taxi limit speed, V_T. For pivoting, define the extent of applicability. Braking after an aborted takeoff on paved and semiprepared airfields shall be at speeds up to the liftoff limit speed, V_{LO}. Braking after landing on paved and semiprepared airfields shall be at speeds up to the touch-down limit speed, V_{TD}. The static ground conditions of MIL-A-8862 and MIL-A-8863, which include two-point braking, reverse braking, unsymmetric braking, and three-point braking, are to be considered.

REQUIREMENT LESSONS LEARNED (A.3.4.2.4)

A.3.4.2.5 Takeoffs.

a. Hard surface runways. (____) Takeoffs from ________________.

b. Semi-prepared runways. (____) Takeoffs from ________________.

c. Unprepared surfaces. (____) Takeoffs from ________________.

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d. Takeoff brake release of _______________.

e. Catapult launch. (____) _______________.

f. Catapult assist ramps. (____) _______________.

g. Assisted takeoff. (____) _______________.

h. Ski-jump. (____) _______________.

i. Other takeoff conditions. (____) _______________.

REQUIREMENT RATIONALE (A.3.4.2.5)

The purpose of this requirement is to establish structural requirements for takeoff operations on specified surfaces.

REQUIREMENT GUIDANCE (A.3.4.2.5)

Define the takeoff requirements in terms of required parameters of 3.2 and 3.3, and rational combination thereof. Takeoff structural requirements shall be based on operational requirements, such as runway conditions. Takeoff conditions shall be at speeds up to those of 3.2.7. For hard surface runways, semi-prepared runways, and unprepared surfaces, define the extent of applicability. For example, takeoffs on semi-prepared runways shall be at speeds up to the lift-off limit speed, V_{LO}. For launch and assisted takeoff, define the extent of applicability. For example, catapult launch shall be at speeds up to the maximum specified launch speed. Further guidance on catapult launch loads is presented in 3.4.2.7. For aircraft required to takeoff from ships with either catapult assist ramps or ski-jump, structural requirements and entry speed limitations shall be established.

REQUIREMENT LESSONS LEARNED (A.3.4.2.5)

A.3.4.2.6 Landings.

a. Hard surface runways. (_____) Landings on __________________.

b. Semi-prepared runways. (_____) Landings on _______________.

c. Unprepared surfaces. (_____) Landings on _______________.

d. Arrestment. (_____) __________________.

e. Decelerating devices. (____) _______________.

f. Other landing conditions. (____) _______________.

REQUIREMENT RATIONALE (A.3.4.2.6)

The purpose of this requirement is to establish structural requirements for landing operations on specified surfaces.

REQUIREMENT GUIDANCE (A.3.4.2.6)

Define the landing requirements in terms of required parameters of 3.2 and 3.3, and rational combinations thereof. Landing structural requirements should be based on operational requirements such as runway and tire conditions. Landings shall be at and up to appropriate speeds of 3.2.7. For hard surface runways and unprepared surfaces, define the extent of applicability. For example, landings on unprepared surfaces shall be at speeds up to the touch-down limit speed, V_{TD}. Further guidance on landing impact loads is presented in 3.4.2.7. For arrestment and decelerating devices, define the extent of applicability. For example, arrestment landings shall be made at speeds up to the maximum specified arrestment speed. Further

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guidance on arrestment loads is presented in 3.4.2.7. NACA TN 3541, NASA TN D-527, AFFDL-TR-68-96, and AFFDL-TR-71-155 provide further insight in establishing landing criteria.

REQUIREMENT LESSONS LEARNED (A.3.4.2.6)

Runway roughness need not be accounted for during landing impacts on hard surface runways or semi-prepared matted field runways. Flight testing of large transport aircraft has demonstrated no increase in design landing loads for matted field runways as compared to hard surface runways. The primary effect of increased runway roughness is an increase in the landing runout repeated loads.

However, unprepared surfaces with large magnitude discrete bumps could cause significant increases in landing impact loads for a given gross weight and rate of sink, requiring either a reduction in the design landing weight or rate of sink for unprepared surface operations, or an increase in structural strength.

A.3.4.2.7 Dynamic response and stability during ground/ship-based operations. (______)

The dynamic response of the air vehicle resulting from ground operations and transient or sudden application of loads shall be included in the determination of design loads. In addition, the air vehicle shall be free from any static or dynamic instabilities.

a. Dynamic response conditions. __________________.

b. Shimmy. During all ground operations (taxi, take-off, and landing), all landing gears as installed in the air vehicle shall be free from shimmy, divergence, and other related gear instabilities for all attainable combinations of configurations, ground operation speeds, loadings, and tire pressures. This requirement shall apply for both normal and failure operations. For the nose gear, the steering system shall be considered ON or OFF and also failed. The design of the landing gear systems as installed shall meet the damping requirement of the Landing Gear Systems Specification as tailored from 3.2.1.4 of AFGS-87139A.

REQUIREMENT RATIONALE (A.3.4.2.7)

The purpose of this requirement is to establish the maximum loads resulting from dynamic response of the air vehicle during ground/carrier operations and to ensure that the air vehicle response is stable throughout these operations. The stability requirement is intended to more clearly focus on shimmy and other landing gear dynamic response problems.

REQUIREMENT GUIDANCE (A.3.4.2.7)

Define the dynamic response conditions of the air vehicle in terms of required parameters of 3.2 and 3.3, and rational combinations thereof. These loading conditions include arresting loads, catapult loads, dynamic taxi loads, and landing impact loads. The arresting loading conditions shall be determined based on the type of ground arrestment system specified by the procuring activity. The magnitude, directions, and distribution of external and internal loads shall be all loads which occur throughout the arresting operation. The determination of these loads shall take into account the time histories of the arresting forces and the resultant response of the airplane structure, with appropriate consideration of the characteristics of tire, shock absorbing, and damping devices.

The catapult loading conditions shall be determined based on the type of catapult launching equipment specified by the procuring activity. The magnitude, directions, and distribution of external and internal loads shall be all loads which occur throughout the catapult operation. The determination of the loads shall take into account the motion of the airplane during the

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catapult run and shall include the effects of launches at 1.2 times the maximum gross weight to assure that overweight launches with increased winds are feasible.

The dynamic taxi loads shall be determined by a dynamic taxi analysis using both a continuous runway profile and discrete step and (1-cosine) bump and dip inputs. This analysis must account for pitch, translation, and roll rigid body modes and all significant flexible modes. The gear's complete nonlinear air spring and hydraulic damping of the oleo and tire must be included. Aerodynamic lift and engine thrust shall be included and all combinations of gross weight, fuel weight, taxi speed and c.g. consistent with planned usage shall be considered. Runway profile elevations used in the continuous analysis shall have power spectral densities (PSD) which equal or exceed the spectra for paved, semiprepared, and unprepared airfields which are presented in figures 12 though 14. The terrain roughness contours used to define airfield surfaces for the discrete input shall consist of step inputs and single and double (1-cosine) shaped bumps and depressions. The step inputs shall be up to 1 inch for paved, 2 inches for semiprepared, and 4 inches for unprepared surfaces. The maximum amplitudes for the bump and depression inputs shall be those of the applicable surfaces for slow and high speed taxi as presented in figures 4 and 5. The aircraft shall approach the contours at all critical angles from 0° to 90° to the crestline of the contours.

The landing impact loads shall be determined by a rational dynamic landing analysis which takes into account the characteristics of the aircraft landing gear and realistically models air vehicle response during landing impact. The magnitude, directions, and distribution of external and internal loads shall be all loads which occur during landing impact. If the landing gear is located on the wing, dynamic loads imposed on a wing during landing impacts may result in more critical wing down loads and wing-mounted store loads.

The damping requirement specified in 3.2.1.4 of AFGS-87139A is necessary to establish an acceptable level of dynamic stability. The primary concern is the damping of steered landing gear to prevent shimmy. The system shimmy stability requirements shall be determined by a nonlinear dynamic analysis which properly accounts for torsional freeplay, Coulomb friction, wheel unbalance, and the capability to assess the effect of a velocity squared damper. The structural model should include effective masses and inertias, structural damping, structural stiffnesses, and gyroscopic effects of the rotating wheel assembly. The tire shimmy model should be either the Von Schlippe Dietrich or the Moreland model. Excitation of the shimmy analysis model shall include impulse, cyclic, and initial displacements of the landing gear. Ground tests to support development of the landing gear analysis model includes ground vibration tests (GVT), structural stiffness parameter tests, tire parameter tests, and dynamometer tests.

REQUIREMENT LESSONS LEARNED (A.3.4.2.7)

Recurrent landing gear shimmy problems have occurred during the development of many aircraft systems. These problems have caused significant impacts on program cost and schedule as well as overall aircraft integrity and performance. Because of these problems, the need to focus on a structured approach to prevention of landing gear shimmy is required. The structured approach should consist of a total quality systems approach which integrates the landing gear design into the overall aircraft design, utilizes a standardized analytical approach in defining landing gear shimmy characteristics, and requires both dynamometer testing early in the landing gear development phase and aircraft ground operations tests.

The need for a requirement which consists of an integrated design approach is clearly demonstrated by an inadequate main landing gear design process used on a large cargo aircraft. The process consisted of providing the landing gear developer with fixed design loads and spatial constraints with no requirement for dynamic stability. The design process did not

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allow feedback to assess the adequacy of the design. This process proved to be inadequate because of many main landing gear shimmy incidences which occurred later in the aircraft test program.

Historically, shimmy analyses have not followed a well defined standardized approach in determining landing gear shimmy characteristics. A number of these analyses have not properly considered items such as nonlinear effects, structural damping, structural stiffnesses, freeplay, and the capability to assess the effect of a velocity squared damper. Landing gear tests have shown that a large number of parameters such as tire and structural stiffness, tire and structural damping, and tire shimmy properties vary in a nonlinear manner as a function of strut stroke position. Experience has shown that landing gear structural damping can vary anywhere from 1 to 10% of the critical viscous damping. The amount of damping during any given taxi run is not constant and can vary between these two percentages. Stability predictions made for a prototype fighter were based on an assumption of a constant 7% critical viscous damping. This assumption resulted in erroneous analytical predictions which overestimated the shimmy stability of the landing gear. The analysis agreed with experimental data when an assumption of 1% damping was used. It is generally recommended that a 1% assumption will expose any potential sensitivity that the landing gear might have toward shimmying.

Finite element analyses used to predict landing gear structural stiffness parameters have not always proven to be reliable. Further, these analyses have consistently predicted the structure to be stiffer than what it really is. Use of these stiffer values in the shimmy analysis will generally lead to overconfidence in landing gear stability. This problem has been observed on a large cargo aircraft, a prototype trainer, and a low observable air superiority fighter.

Landing gear torsional freeplay can significantly affect analytical stability predictions and should always be considered in the development of shimmy analyses. Experience indicates that a reasonable range of freeplay on a new landing gear is from an absolute minimum of .5 and is generally not larger than 2 degrees. Some landing gears are extremely sensitive to increasing torsional freeplay while some do not seem to be affected by it. For example, the nose gear of an air superiority fighter was extremely sensitive to small torsional freeplay variations. On the other hand, the nose gear of a prototype trainer was totally insensitive to the freeplay range cited above. Therefore, a freeplay sweep in the shimmy analysis to determine landing gear dynamic response sensitivity over the design speed range of the gear is recommended.

Velocity squared shimmy dampers have shown themselves to be useful on marginally stable landing gears in spite of added weight and tire wear penalties. Therefore, a standardized shimmy analysis should include consideration of this option to demonstrate that adequate damping is achieved if a velocity squared shimmy damper is used.

While shimmy analysis with analytically derived input data may be useful in identifying major problems of the gear early in the design stage, this approach does not provide a sufficient level of accuracy in the prediction of physical stability characteristics. For this reason, testing of an actual gear is needed to establish further confidence in the analysis. This testing includes ground vibration test (GVT), structural stiffness parameter tests, tire parameter tests, and dynamometer tests.

The GVT is conducted to measure landing gear mode shapes, frequencies, and modal damping for the fore and aft, lateral, and torsional modes of the main and auxiliary landing gears. During these tests, the wheels shall be free from the ground. The test results shall be used to verify all dynamic response analyses. Where applicable, results of the GVT shall be used in resolving and preventing transient vibration problems due to brake chatter, gear walking, antiskid control, wheel unbalance resonances, and shimmy.

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Structural stiffness tests are conducted to determine the accuracy of the original stiffness values obtained from the finite element analysis. A common approach used in making these measurements is to input forces to the gear and measure the resulting deflections. A frequent oversight consists of ignoring the stiffness contribution of the fuselage backup structure. If appropriate fuselage backup structure is unavailable during these tests, then a compliant structure which simulates the flexibility of the fuselage structure shall be inserted as an interface between the landing gear and the test support structure. Because of difficulties associated with predicting structural flexibilities, sensitivity studies which consider a range of flexibilities should be conducted to determine the effects of flexibility variations on the stability of the landing gear design. Design of the compliant structure should be based on results of the sensitivity studies and subject to the approval of the procuring agency.

Tire parameter tests are conducted to determine the specific parameters associated with the selection of either the Von Schlippe Dietrich or the Moreland tire model over the range of loading conditions and tire pressures which the tire will experience in actual operations. The specific parameters associated with the Von Schlippe Dietrich tire model are provided in NACA TR-1299. The Moreland tire model parameters are provided in "The Story of Shimmy" by William J. Moreland.

Dynamometer tests are conducted to determine the overall dynamic stability of the landing gear and to identify potential design changes earlier in the development phase to help minimize cost and schedule impacts. These tests are recommended to support risk management, enhance experimental repeatability, and measurement reliability in a controlled laboratory environment. However, some caution must be used in setting up a dynamometer test. The landing gear cannot simply be rigidly mounted to a platform above the dynamometer. Instead, compliant structure must be inserted between the platform and the landing gear to properly simulate the fuselage backup structural flexibility. Experience indicates that the stiffness values obtained from both a rigidly mounted gear and actual aircraft are nonlinear and vary with stroke position. Also the rigidly mounted gear values will be in error by as much as 300% when compared to the values obtained on the actual aircraft. The dynamometer test conditions should include runs with and without excitation forces applied either at the farthest axle from the primary landing gear post or at the primary landing gear post. The location selected should produce the greatest excitation to the gear structure. The forcing mechanism used in the dynamometer tests should be capable of applying either a single or cyclic impulse to the gear with sufficient force to insure that breakout from the torsional friction binding occurs. For cyclic impulses, care should be taken in the design of the mechanism to insure that it recoils faster than the gear does to prevent interference with the natural motion of the gear. Experience indicates that the dynamometer test matrix should include ten knot speed increments, at least four strut stroke positions, and at least three tire pressures to prevent overlooking a critical shimmy speed, to account for nonlinear effects, and to assure that aircraft weight configurations are adequately represented by these tire pressures.

A.3.4.2.8 Ski equipped air vehicles. (____)

a. Frozen skis. ________________.

b. Ski load distribution conditions. ________________.

REQUIREMENT RATIONALE (A.3.4.2.8)

The purpose of this requirement is to establish structural requirements for ski equipped aircraft operating on snow, ice, and mud.

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REQUIREMENT GUIDANCE (A.3.4.2.8)

If the subparagraphs are applicable, define the requirements in terms of required parameters of 3.2 and 3.3, and rational combination thereof. Ski structural requirements shall be based on operational requirements such as taxiway and runway, surface conditions and environmental conditions. Ski requirements should reflect appropriate speeds of 3.2.7. For example, ski equipped air vehicles shall operate in snow, in mud, and on ice. During the takeoff and landing run, the airplane shall be in the three-point attitude. The vertical load factor at the gear shall be 1.0 at the maximum ground weight with a linear variation of load factor to 1.2 at the normal landing weight. The coefficient of friction shall be 0.40. Pitching moment shall be balanced by rotational inertia. For frozen skis, the air vehicle shall be in the three-point attitude with each ski alternately assumed fixed. The loads and torques shall be those resulting from application of maximum engine power or thrust available at -60°F to the engine(s) on the side opposite from the fixed ski. The loads shall be reacted by the main gear ski and nose gear ski and alternately, by the main gear ski alone. The nose-gear ski shall resist full steering torque. Ski load distribution conditions shall be established in accordance with the following:

a. Vertical and side loads resulting from takeoff and landing run shall be distributed as shown on figure 15. Side loads shall be applied on either ski where applicable.

b. Treadwise loads shall be distributed alternately to the inboard and outboard side of the ski as shown on figure 16, except that for rolled attitude landings, the distribution shall be 3 to 1.

c. Drag load shall be distributed uniformly along the base of the ski. Side load and drag need not be combined.

REQUIREMENT LESSONS LEARNED (A.3.4.2.8)

The criteria suggested above have been used previously and have proven adequate for operations on normal snow surfaces. The criteria have proven inadequate for operations on rough hard packed snow containing blocks of ice and for loose, deep snow containing sastrugi ridges of greater than 12 inches. The criteria are adequate for heavy gross weight operations on smooth, well maintained skiways, where a smooth skiway is defined as one which has been graded a surface free of hardened snowdrifts, ice blocks, pressure ridges, mounds of snow, and sastrugi ridges and which has changes in elevation not exceeding four inches in twenty feet.

A.3.4.2.9 Maintenance.

a. Towing. (_____) ____________________.

b. Jacking. (_____) ____________________.

c. Hoisting. (_____) ____________________.

REQUIREMENT RATIONALE (A.3.4.2.9)

The purpose of this requirement is to establish structural requirements for specified maintenance conditions.

REQUIREMENT GUIDANCE (A.3.4.2.9)

Define the maintenance requirements in terms of required parameters of 3.2 and 3.3, and rational combination thereof. Maintenance requirements should be based on operational requirements such as towing, jacking, and hoisting. For example, towing, jacking, and hoisting loads shall be established in accordance with the following:

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a. Towing. The air vehicle shall be in a three-point attitude. The resultant of the vertical reactions at the wheels shall be equal to the weight of the aircraft and shall pass through the cg. The towing conditions shall be specified in table XII. The values of T used in obtaining the loads specified in table XII are those defined on figure 17. These towing loads shall act parallel to the ground. The side component of the tow load at the main gear shall be reacted by a side force at the static ground line at the wheel to which the load is applied. Additional loads necessary for equilibrium shall be applied. Review and include as applicable the Standardization Agreement 3278ASP on towing attachments on aircraft.

b. Jacking. Jacking loads shall be in accordance with table XIII. The vertical load shall act singly and in combination with the horizontal load acting in any direction. The horizontal loads at the jack joints shall be so reacted by inertial forces that there will be no change in the vertical loads at the jack joints. The maximum landing gear jacking weight is specified in 3.2.5.10 and the maximum airframe jacking weight is specified in 3.2.5.11. Review and include as applicable the Standardization Agreement 3098ASP on aircraft jacking.

c. Hoisting. When the aircraft is in the level attitude, the vertical component shall be 2.0 W_H. The maximum airframe hoisting weight, W_H, is specified in 3.2.5.12.

REQUIREMENT LESSONS LEARNED (A.3.4.2.9)

The dynamic magnification factors used in establishing jacking loads and hoisting loads have been substantiated by dynamic analyses conducted on various types of aircraft.

A.3.4.2.10 Ground winds.

a. Ground operations. ______________.

b. Maintenance. ______________.

c. Parked, unattended. ______________.

d. Tied-down. ______________.

e. Jet blast. (____). ______________.

REQUIREMENT RATIONALE (A.3.4.2.10)

The purpose of this requirement is to establish structural requirements for ground and shipboard winds for ground/shipboard operations as well as operational maintenance in normal and adverse weather conditions.

REQUIREMENT GUIDANCE (A.3.4.2.10)

Define ground and ship wind requirements in terms of required parameters of 3.2 and 3.3, and rational combination thereof. Wind structural requirements shall be based on operational requirements such as prelaunch and recovery requirements, operational maintenance, and adverse weather operations. During normal operations, the airplane shall be subjected to horizontal tail winds and crosswinds. For example, ground wind on longitudinal, lateral, and directional control surfaces shall be a 70 knot horizontal tail wind (including a 25 percent gust). With the air vehicle on the ground at zero ground speed and all engines delivering thrust or power required for takeoff, the air vehicle shall encounter a horizontal wind (including a 25 percent gust) at 70 knots in all directions within +/-45 degree from dead ahead. During maintenance, the airplane shall be subjected to ground winds from any horizontal direction. For example, external doors and radomes shall be subjected to winds, while in their open and any intermediate positions, of 50 knots (including a 25 percent gust) from any horizontal direction. The doors and radome actuating mechanisms shall be able to operate during 35 knot steady

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wind in any horizontal direction combined with a vertical load factor of 1.0 +/-0.5g and a horizontal load factor (in the most critical direction) of +/-0.5g. When parked and unattended, the airplane shall be subjected to ground winds from any horizontal direction of 50 knots (including a 25 percent gust). When tied-down, the airplane shall be secured in the static attitude and with control surfaces locked and battens in place and shall be subjected to a 70 knot wind (including a 25 percent gust) from any horizontal direction. For jet blast, define the extent of applicability. Jet blast requirements shall reflect for operational requirements such as close proximity to other operating jet aircraft.

During shipboard operations, control surface and folded surface loads will result from a combination of inertial loads resulting form ship motion and air loads resulting form the combination of wind over deck (natural winds plus ship speed) as well as superposition of engine exhaust of adjacent aircraft (catapult launch near JBD). Tables I and II of MIL-T-81259A provides combinations of inertia load factors and wind speeds for various ships and weather conditions.

REQUIREMENT LESSONS LEARNED (A.3.4.2.10)

During maintenance, large aircraft may be positioned inside a building with the fuselage aft body and empennage protruding. The resultant jack/landing gear reactions will differ from those which occur when the entire aircraft is exposed to the ground winds. In particular, the aerodynamic yawing moment is typically higher for the condition where only the empennage and fuselage aft body are exposed to the ground winds rather than the entire airplane. During taxi in carrier deck, engine exhaust has caused static failure or high temperatures to be experienced on adjacent aircraft.

A.3.4.2.11 Crashes. (____)

The airframe shall be able to withstand crashes so as to protect personnel to the extent reflected by the following ultimate loading conditions and parameters. The airframe shall not inhibit personnel egress from an airframe within ________________.

a. Seat installations. The seat occupant shall not be injured by airframe/seat support installation deformations or failures resulting from ____________.

b. Fuel tanks and installations. The airframe shall not inhibit fuel containment for conditions of ___________.

c. Fixed and removable equipment. ___________________.

d. Cargo. (____). ___________________.

e. Litters. (____). ___________________.

f. Bunks. (_____). ___________________.

REQUIREMENT RATIONALE (A.3.4.2.11)

The purpose of this requirement is to establish crash load factors for structural requirements of airframe installations and backup structures required to protect personnel during crash landings.

REQUIREMENT GUIDANCE (A.3.4.2.11)

Define crash requirements in terms of longitudinal, vertical, and lateral crash load factors. These crash load factors are ultimate load factors required for strength of airframe installations and back-up structures which are required to protect personnel during crash landings. The crash load factors result from air vehicle impact conditions of flight path velocity, air vehicle

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attitude, and terrain conditions which should be defined in such a manner that personnel survivability can be attained with reasonable and practical structural considerations. The airframe should provide a protective shell surrounding the personnel, and should minimize the loads experienced by personnel so that (hopefully) they will be less than human tolerance limits. Mass items are to be supported in such a manner so as to prevent lethal or injurious blows to personnel. Deformations of the seat shall occur in such a manner as to prevent injury or incapacitation of personnel. Restraint of personnel motion shall be provided so as to minimize the effect of blows as a result of contact with surrounding structure. Egress time from an intact airframe shall be established based upon trade studies which take into consideration-crash attitudes and associated weight penalties. These trade studies should be compatible with system safety requirements. The blanks for seat installations, fuel tanks and installations, and fixed and removable equipment shall be completed with the appropriate load factors selected in accordance with the following:

a. Seat installations. These shall include pilot, crew, passenger, troop, and ejection seat. The minimum longitudinal, vertical, and lateral load factors shall equal the ultimate load factors required for strength of crew and passenger seats as specified in the applicable specifications for such seats or shall be in accordance with table XIV if seat specification is not available. The ultimate loads shall be based on load factor times the combination of an appropriate amount of seat mass, the man plus personal equipment as shown in AFSC DH 2-1 and the weight of any seat armor when used. Seat attachments to the floor shall be able to withstand these loads.

b. Fuel tanks and installation. Fuel tanks will provide a high degree of fuel containment during a crash. All internal fuel tanks, including all critical amount of fuel up to two-thirds of the individual tank capacities, shall be able to withstand the ultimate load factor requirements as determined by analysis and trade studies or as provided below.

c. Fixed and removable equipment. All fixed and removable miscellaneous and auxiliary equipment and their subcomponent installations, including but not limited to, provisions for the restraint of engines, fuel tanks, armament avionics, equipment, consoles, static lines, parachute airdrop shackle, emergency and survival equipment, escape capsule/fuselage attachment devices, retention system components for tools, ground handling implements and other portable items, and mechanisms for operating and holding open canopies, doors, and other exits for egress, which in the event of a crash could result in injury to personnel or prevent egress from a crashed airplane, should be able to withstand the air vehicle load factors, the results of the analysis and trade studies or the following load factors, as applicable:

Longitudinal	9.0 forward, 1.5 aft
Lateral	1.5 right and left
Vertical	4.5 down, 2.0 up

Where fixed and removable equipment is located in a manner wherein failure could not result in injury to personnel or prevent egress, their respective airframe attachments and carry through structures should be able to withstand the air vehicle design load factors, the results of the trade studies, or the following ultimate load factors, as applicable:

Longitudinal	3.0 forward, 1.5 aft
Lateral	1.5 right and left
Vertical	4.5 down, 2.0 up

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For cargo, litter, and bunks, define the requirement by selecting the appropriate crash load factors. The load factors for cargo must be defined for nonpersonnel cargo and also for nonpersonnel cargo in collocation with personnel cargo. Cargo load factors should be established based upon trade studies which take into account crash attitudes, risks and associated weight penalties, and are compatible with the system safety requirements. Current cargo aircraft are structured to withstand the following non-nuclear, nonpersonnel cargo load factors:

Longitudinal	3.0 forward, 1.5 aft
Lateral	1.5 right and left
Vertical	4.5 down, 2.0 up

These current crash load factors for cargo are the subject of international standardization agreements ASCC Air Standard 44/12 and STANAG 3400. When crash load factors are selected which will affect or violate the international agreement concerned, the preparing activity will take appropriate reconciliation action through international standardization channels, including departmental standardization offices, if required. Cargo restraint criteria are addressed in AFSC DH 2-1 and ASCC Air Standard 44/17.

REQUIREMENT LESSONS LEARNED (A.3.4.2.11)

Air Force studies have concluded that a reduction in forward restraint of nonpersonnel cargo from 4g to 3g would not alter the level of protection provided to the aircrew.

A.3.4.2.12 Ditching. (_____)

The structural integrity of the air vehicle shall be maintained during ditching operations in order to protect personnel and allow successful egress and deployment of survival equipment. The water pressures specified in ________ shall be used for structural design.

REQUIREMENT RATIONALE (A.3.4.2.12)

The purpose of this requirement is to establish the ditching loads necessary for structural design of airframe installations and backup structure required to protect personnel during ditching operations.

REQUIREMENT GUIDANCE (A.3.4.2.12)

Define the requirement for ditching in terms of water pressures combined with ditching load conditions derived from critical combinations of required parameters 3.2 and 3.3. The ditching conditions are subject to approval of the procuring agency. The water pressures specified in table XV may be used for structural design. These water pressures are the dynamic pressures exerted on the airframe as it moves through the water during ditching operations. Structural areas and backup structure such as, but not limited to, bomb bay doors, hatch covers, windows, wheelwell covers, and other fuselage cutout areas, shall not fail under the specified pressures. A failure in the structural areas is one that would cause an undesirable behavior of the aircraft during ditching operations or allow rapid entry of water. Doors shall be equipped with catches and hinges which have adequate strength to preclude door failure or opening during ditching operations. Aircraft underside protuberances such as landing flaps and underslung parts shall have supporting structures which are designed to allow either their removal or retraction upon contact with the water to prevent noseover. Ducts and vents shall be designed to prevent rapid water ingress. Escape-hatch and life-raft compartment doors shall be designed to preclude their nonoperation through jamming or structural damage.

REQUIREMENT LESSONS LEARNED (A.3.4.2.12)

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A.3.4.2.13 Other ground loading conditions. (____)

REQUIREMENT RATIONALE (A.3.4.2.13)

The purpose of this requirement is to establish structural requirements for other ground loading conditions such as hail damage, arrested landing, and repaired bomb damaged runways.

REQUIREMENT GUIDANCE (A.3.4.2.13)

For other ground loading conditions, define the requirement in terms of required parameters of 3.2 and 3.3 and rational combinations thereof. Other ground loading conditions shall include consideration of system failures (3.2.22).

REQUIREMENT LESSONS LEARNED (A.3.4.2.13)

A.4.4.2 Ground loading conditions.

Analyses and tests shall be of sufficient scope to determine and verify the loads resulting from and commensurate with the ground loading conditions of 3.4.2. Dynamic analyses and tests are also required to verify that the air vehicle is free from dynamic instabilities which could impact ground/ship based operations.

VERIFICATION RATIONALE (A.4.4.2)

This verification task is required so that the ground loading conditions are appropriately determined and formally established to assure that the airframe has adequate structural integrity for its required service usage. It is also required to verify that the air vehicle is free from dynamic instability problems which could cause significant impacts on program cost and schedule as well as overall aircraft integrity and performance.

VERIFICATION GUIDANCE (A.4.4.2)

Aircraft ground and dynamic response analyses and tests which reflect ground/ship based operations must be conducted to determine the adequacy of the design loads analyses and verify the structural integrity of the aircraft. The ground and dynamic response tests should be sufficient in scope to assure that all critical design loads are established. These tests will consist of measuring loads and dynamic responses on an instrumented and calibrated test aircraft during ground operations such as taxi, takeoff, landing, and towing.

Prior to the tests, the dynamic stability of the test aircraft shall be verified to insure that the air vehicle is free from shimmy, divergence, and other related gear instabilities for all attainable combinations of configurations, speeds, loadings, and tire pressures. Verification shall consist of taxiing the test aircraft over various bump configurations. These bumps should be angled with respect to the forward direction of the aircraft to maximize the likelihood of breakout from torsional binding friction. Instrumentation on the landing gear will be required to measure the amount of torque supplied to the gear during bump encounter. The bump configurations are defined by bump spacings and bump heights. Bump spacings are determined by dividing the aircraft's constant forward speed by the frequency obtained from the shimmy analysis. Bump heights are determined analytically by the amount of torque required to assure breakout from torsional binding friction of the landing gear. Maximum bump heights used should not exceed the landing gear and backup structural design capability. The results of the dynamic stability test are required to update the shimmy analysis which will be used for verification of all nontested aircraft configurations. Further guidance on aircraft ground tests can be found in the Verification Guidance of 4.4. General guidance on shimmy testing is presented in WADC TR-56-197.

VERIFICATION LESSONS LEARNED (A.4.4.2)

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Dynamic taxi analyses have been performed for continuous runway profiles, discrete bumps, and 1-cosine bumps and dips of wavelengths tuned to produce maximum aircraft loads. These analyses have resulted in limit loads throughout the airframe and are considered very necessary to the early establishment of confidence in the structural integrity of the airframe. The dynamic taxi analyses should be used to investigate the effects of realistic bomb damage repaired airfield surface profiles in which the structural integrity of the airframe air vehicle is expected to operate in a hostile environment. Dynamic taxi analyses must account for pitch, translation, and roll rigid body modes and all significant flexible modes. The gear's complete nonlinear air spring and hydraulic damping of the oleo and tire must be included. Aerodynamic lift and engine thrust shall be included and all combinations of gross weight, fuel weight, taxi speed, and c.g. consistent with planned usage shall be considered.

When using the power spectral density method of evaluating aircraft response, the assumptions of a stationary, Gaussian random process and a linear system are seldom justified. Nevertheless, the method is useful in estimating repeated loads effects since it yields the average or root mean square value of the response. For a better estimation of peak loads and to better account for the non-linearities of a landing gear system, air vehicle taxi model may be excited by a runway unevenness profile generated from the specified runway roughness PSD. Many profiles can be generated which exhibit the roughness characteristics of the specified roughness PSD, resulting in some variation in peak load conditions. It is, therefore, necessary to study the results of several profiles to be confident that a reasonable estimate of expected peak load is obtained.

Dynamic taxi analyses performed for a strategic aircraft over continuous runway profiles and 1-cosine bumps and dips predicted loads less than those predicted for the 2.0 g static taxi condition.

Quasi-static analyses, using empirical values for vertical and lateral load factors, have proven to yield suitable limit load levels on a number of transport aircraft, including those operating from semiprepared fields. Rational dynamic analyses have generally resulted in loads which were lower in magnitude on most components and hence may be unnecessary for unbraked turns.

A quasi-static analysis or pivoting is considered entirely satisfactory since the very low rates of aircraft rotation do not introduce significant dynamic effects.

Braking loads on past transport aircraft have been based on quasi-static analyses using empirical factors defined in previous specification or elsewhere. The resulting loads have proven adequate for these aircraft. More recent efforts such as the CX proposal have used rational dynamic analyses and have generally yielded loads equal to or less than those derived by the previous methodology. However, recent aircraft taxi test programs have shown that the landing gear struts are likely to bottom if the aircraft is operated on bomb damage repaired or unprepared rough surfaces. The degradation in strut capability is due to air/oil mixing for those struts where air and oil are in contact with each other. Because of this condition, it was determined that braking was a critical operating condition due to degraded strut performance and the increased loads imposed on the nosegear during braking. A rationale dynamic analysis should account for the occurrence of strut bottoming.

The frequency defined by the bump spacing used in a dynamic stability test should be established by shimmy sensitivity studies which will determine the frequency most likely to excite the landing gear. During dynamic stability testing of a large cargo aircraft, the bump spacing was fixed throughout the test. Since the excitation frequency of the landing gear is established by the aircraft forward velocity and the spacing between adjacent bumps, use of a fixed bump spacing did not generate the established excitation frequency. However, during subsequent flight testing conducted later in the program, recurrent shimmy problems occurred

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on all main landing gears. Therefore, the results of the dynamic stability test did not satisfy the shimmy verification requirement. Failure to identify these shimmy problems early in the program resulted in the elimination of more desirable design alternatives. These recurrent problems were simply resolved by use of velocity squared shimmy dampers.

During dynamic response testing, should breakout from torsional binding friction not occur within the range of allowable bump heights, one method which may facilitate landing gear frictional breakout is to use a less frictional lubricant on critical landing gear components. This method of facilitating breakout was accidentally encountered on a large cargo aircraft which recently underwent a new weight off wheels greasing procedure on the main landing gears. However, it should be noted that this approach is suggested only for test purposes. If change in landing gear greasing lubricants are likely to occur as a normal servicing procedure, a sensitivity study should be conducted to assess the impact on landing gear stability.

A.3.4.3 Vibration and aeroacoustics.

Vibration and aeroacoustic loadings shall be combined with the flight and ground loads of 3.4.1 and 3.4.2. Vibration and aeroacoustic loads shall be as required by 3.5 and 3.6.

REQUIREMENT RATIONALE (A.3.4.3)

In general, vibroacoustic and flight loads can be handled separately. However, there are cases when the two loadings in combination will cause failures or operational problems.

REQUIREMENT GUIDANCE (A.3.4.3)

Review the flight and vibroacoustic loadings and determine those areas of the airframe or those combinations of flight or ground conditions where loadings may combine in such a way as to cause failures or operational problems. In these cases, develop design requirements which preclude failure or operational problems due to these combinations of loadings.

REQUIREMENT LESSONS LEARNED (A.3.4.3)

The combination of thermal loads and aeroacoustic loads caused fatigue failures in primary structure very early in the life of a large bomber aircraft. The failures occurred when hot surface flow caused skins to distort sufficiently to introduce high mean stresses in skins. The skins then failed in vibratory fatigue.

Many failures have occurred in propeller aircraft fuselage sidewall structure due to the combination of pressure loads and oscillatory pressure fields associated with propeller blade passage.

A.4.4.3 Vibration and aeroacoustics.

Vibration and aeroacoustics loadings shall be combined with flight and ground loads in accomplishing 4.4, 4.4.1, and 4.4.2. Vibration and aeroacoustic loads shall be as required by 4.5 and 4.6.

VERIFICATION RATIONALE (A.4.4.3)

In most instances, structural, aeroacoustic, and vibration loadings are effectively evaluated separately. However in a few cases these loadings interact such as to require design and verification analyses and tests to include them simultaneously.

VERIFICATION GUIDANCE (A.4.4.3)

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Evaluate the need for simultaneous application of structural, aeroacoustic, and vibration loadings.

VERIFICATION LESSONS LEARNED (A.4.4.3)

A large bomber aircraft developed cracks in a structural deck due to the simultaneous application of flight loads, thermal loads, and aeroacoustic loads. Very extensive combined loading analyses combined with laboratory tests were conducted to develop a design change to eliminate the problem. The problem was exacerbated by the extreme difficulty in measuring and reproducing the complete environment. The design change was a costly retrofit of large sections of major structure. If the original design had been properly based on the combined environments the problem could have been avoided with very little weight, or cost impact and no schedule impact.

A.3.5 Aeroacoustic durability.

The airframe structure shall operate in the aeroacoustic environments which are commensurate with the required parameters of 3.2 and 3.3, and rational combinations thereof without failure as described herein. Aeroacoustic loads sources include: _______________.

REQUIREMENT RATIONALE (A.3.5)

This paragraph provides the possible sources of aeroacoustic loads which can cause structural damage and adversely effect the structural integrity of the airframe.

REQUIREMENT GUIDANCE (A.3.5)

Identify the aeroacoustic loads sources associated with the air vehicle and its usage. Some sources of aeroacoustic loads to which the airframe may be exposed are listed below.

a. Propulsion system noise; for example jet or rocket noise, fan and compressor noise, thrust reverser noise, and propeller noise. Consider increases in noise levels on the airframe caused by the use of ground noise suppressers.

b. Power lift systems; for example, externally blown flaps and jet flaps.

c. Boundary layer pressure fluctuations arising from high dynamic pressure and transonic flight conditions and separated flows due to protuberances or discontinuity in external surfaces.

d. Cavity noise; for example, open weapon bays and compartments open to external flow.

e. Blast pressures due to armament usage; for example, gunfire and rocket firing.

f. Aeroacoustic loads in ram air ducts, inlets, air conditioning ducts, plenums, and fans.

g. Aeroacoustic loads caused by auxiliary power units, motors, and pumps.

h. Jet exhaust turbulence noise experienced when the air vehicle is in launch position on shipboard catapult with the jet blast deflector (JBD) raised, and when the air vehicle is behind the raised JBD in position for the next launch. Time of exposure for these conditions are as follows.

(1) Thirty seconds of maximum power when in launch position on shipboard catapult.

(2) Thirty seconds behind raised JBD when in position for next launch.

i. Jet engine exhaust and temperature.

REQUIREMENT LESSONS LEARNED (A.3.5)

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Neglecting the contribution of a potentially damaging source can result in redesign or intolerable maintenance problems. Though propulsion system noise is usually obvious, other sources have often been overlooked. Separated flow is often the dominant source in modern high performance aircraft. Levels can be as high as propulsion system noise and more time may be accumulated with in flight separated flow conditions than at takeoff. For example, structural damage has occurred behind speed brakes and separated flow from the chin pods or fairings.

Separated flows can also be encountered on the outboard wing surfaces during high dynamic pressure and high angle of attack maneuvers.

Fan noise has produced cracks in the intake ducts and in inlet guide vanes.

Bomber aircraft have encountered significant problems due to large open weapon bay oscillating pressure levels. In some cases, the disturbance extended to the complete aircraft and ride quality was affected. In addition, weapon bay pressure levels can be of sufficient magnitude to damage the structure of the weapon bay, weapon bay doors, and weapons. Narrow band resonant amplification of pressure levels subjecting structure and equipment to pressure amplitude as much as 10 times the background level has been encountered in small cavities. Cavity resonance suppression (via spoilers, etc.) should be considered to avoid weapons bay and internal noise, vibration, and aeroacoustic fatigue.

A.4.5 Aeroacoustic durability.

Analyses and tests shall verify that the airframe can operate in the aeroacoustic environment associated with operational use as required by 3.5.

VERIFICATION RATIONALE (A.4.5)

The sources and criteria form the basis of the aeroacoustic durability of the airframe.

VERIFICATION GUIDANCE (A.4.5)

Check predicted durations, spatial distributions, and frequency distributions of the aeroacoustic loads from each applicable source identified in 3.5. Update parameters when changed usage or configuration modifications cause them to change. Replace predictions with measured data when it becomes available.

VERIFICATION LESSONS LEARNED (A.4.5)

Few air vehicle programs end with the initial configuration. Subsequent modifications or additions of structure or equipment require the application of the best available criteria for aeroacoustic durability. Up-to-date criteria forestalls costly retrofit changes.

A.3.5.1 Structure.

The airframe structure shall withstand the aeroacoustic loads and the vibrations induced by aeroacoustic loads for the service life and usage of 3.2.14 without cracking or functional impairment. For design, an uncertainty factor of ___ shall be applied on the predicted aeroacoustic sound pressure levels. For design fatigue life, a factor of ___ shall be applied on the exposure time derived from the service life, and usage of 3.2.14.

REQUIREMENT RATIONALE (A.3.5.1)

Safety considerations require that primary load bearing structures be fatigue resistant for the desired service life. Maintenance considerations also dictate that components possess a full service life. The objective of WADC-TM-58-4 was to control aeroacoustic fatigue to prevent a maintenance burden, determine how and when to inspect and repair, and prevent safety of

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flight failures. In MIL-A-8870(ASG), the concept of preventing any aeroacoustic failures was introduced. The succeeding specifications, MIL-A-8870B(AS), MIL-A-8870C(AS) and MIL-A-8893, were aimed at prohibiting fatigue failures during the airframe service life or the life for replaceable parts.

Uncertainty factors are necessary in the application of aeroacoustic loads and durations. This is because current and near term state-of-the-art aeroacoustic and vibratory fatigue analysis, prediction, and measurement technology are not adequate to provide sufficient operational life unless factors are applied.

REQUIREMENT GUIDANCE (A.3.5.1)

Fill the first blank with +3.5 dB unless a smaller factor can be fully substantiated based on proven improvements in state-of-the-art technology, exceptionally well defined environments, or exceptionally complete test data.

Fill the second blank with 2.0 unless fatigue design data (S-N curves) represent documented lower bound (-3.0 sigma) material properties.

REQUIREMENT LESSONS LEARNED (A.3.5.1)

The most common types of aeroacoustic failures are encountered in skin panels and support structure including stiffeners and rivets. During the full scale test of a large bomber aircraft, a total of approximately 700 failures occurred in 10 hours of maximum engine power.

Experience over many years and many programs has consistently shown that capabilities to measure, analyze, and reproduce aeroacoustic loads and to analyze vibratory fatigue are not adequate without factors of uncertainty. In addition, forecasted improvements in the state-of-the-art will only slowly decrease this uncertainty.

A.4.5.1 Structure.

Analyses and tests shall verify that the structure meets the requirements of 3.5.1.

A.4.5.1.1 Analyses.

Near field aeroacoustic loads shall be predicted for the air vehicle for the service life and usage of 3.2.14 and the sources listed in 3.5. Model tests are required where reliable predictions of the environment cannot be made. Analytical predictions of the fatigue life shall be made for all structure exposed to aeroacoustic loads.

VERIFICATION RATIONALE (A.4.5.1.1)

Determining the magnitude of the various aeroacoustic sources allows placing priorities and discovering which sources are insignificant and which need to be emphasized. Wind tunnel or jet models are sometimes necessary to define acoustic levels in cases where prediction methods are inadequate. Accurate fatigue life predictions are needed to design a durable lightweight structure without weight penalties from conservative design compromises, and provide a basis to determine which components are candidates for acoustic testing.

VERIFICATION GUIDANCE (A.4.5.1.1)

The environment due to all applicable sources should be analyzed and predicted. Wind tunnel model tests may be useful in defining aeroacoustic loads resulting from cavities, separated airflow due to protuberances, etc. Jet models may be used to predict acoustic loads from propulsion systems. The accuracy of the aeroacoustic loading is of great importance to fatigue

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life estimation as well as internal noise and vibration environment. The external environment provides the basis for internal noise predictions.

If the measurements of 4.5.1.2.2 and 4.5.1.2.3 indicate that predicted levels are too low, it will be necessary to revise these analyses using the measured data.

VERIFICATION LESSONS LEARNED (A.4.5.1.1)

Experience with bomber aircraft weapon bays has shown that wind tunnel testing is very useful, particularly in regard to studying means of suppressing acoustic disturbances.

Acoustic levels measured or predicted without the presence of the aircraft, must be increased to account for surface effects. For normal incidence impingement, this increment would be 6 decibels (dB) to account for the presence of structure. During ground operations ground reflections must also be accounted for.

Failures in secondary structure have been found to be the most common type of structural failure, e.g., skin panels, skin supports, stiffeners, rivets, etc. Primary structures, designed for large magnitude loading, seldom suffer aeroacoustic fatigue failures.

Spikes (or pure tones) should be evaluated separately. Spikes in spectra with low overall sound pressure levels have caused sonic fatigue failures.

A.4.5.1.2 Tests.

A.4.5.1.2.1 Fatigue tests.

Aeroacoustic fatigue tests shall be performed utilizing the uncertainty factors on sound pressure level and duration specified in 3.5.1. Other simulated environments (such as temperature and pressure differential) combined with the sonic environment shall be imposed when applicable.

A.4.5.1.2.1.1 Component tests.

Aeroacoustic fatigue tests of structural components are required to verify the aeroacoustic fatigue analyses of components including those structures where the fatigue life cannot be adequately predicted, such as new materials or structures of unusual configuration.

VERIFICATION RATIONALE (A.4.5.1.2.1.1)

Component tests are necessary to demonstrate that the structure does meet life requirements in the aeroacoustic environment. In many cases, theoretical analyses are not sufficiently accurate to risk proceeding directly to production without testing. It is estimated that the accuracy of prediction techniques is no better than three to five decibels.

VERIFICATION GUIDANCE (A.4.5.1.2.1.1)

Tests should be performed on fatigue critical structural components and candidate structural designs where basic data such as S-N curves, fatigue data, or experience with the structural configuration do not exist.

VERIFICATION LESSONS LEARNED (A.4.5.1.2.1.1)

Experience has shown that analyses alone are not sufficiently accurate to provide fatigue resistant structure. Structural deficiencies discovered by testing can be economically corrected early in the program.

A.4.5.1.2.1.2 Full-scale tests. (_____)

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Tests of the airframe are required to verify the aeroacoustic durability for the environments based on the flight and ground surveys of 4.5.1.2.2.

VERIFICATION RATIONALE (A.4.5.1.2.1.2)

Full scale tests have been shown to be useful for the following reasons:

a. The acoustical field is reproduced for the takeoff condition and all critical effects are accounted for realistically. In many cases this aeroacoustic field is the most critical and should be full scale tested.

b. Structure and equipment are tested simultaneously as a dynamic system.

c. Repair and maintenance schedules can be more realistically estimated.

VERIFICATION GUIDANCE (A.4.5.1.2.1.2)

The test article should be a complete airframe or a full-scale portion of the airframe. Final determination shall be based on the extent and magnitude of the predicted or measured aeroacoustic loads impact on the structure. If aeroacoustic levels are shown by analysis to be sufficiently low such that no fatigue damage will be expected in the service life, no testing should be required. If relatively minor areas of the aircraft are affected by aeroacoustic fatigue, component test may be sufficient. Examples of specimen candidates are structure near the jet engine exhaust or behind protuberances in high speed flow. Test durations are to be defined based on expected service life exposures. The highest engine noise environment is normally encountered during ground engine use and takeoff. For this condition, the test duration may be determined from:

$$T_D = 0.4\ T_t + T_s$$

T_t is the total takeoff time experienced by the airplane during a service life. T_s is the total time experienced at static maximum engine thrust during a service life. Takeoff time is the time of application of maximum thrust before takeoff roll until liftoff from runway. For other conditions, e.g., areas behind speed brakes, or high aeroacoustic levels caused by high speed flight, actual times should be used for the tests when practical. Increased test levels, when justified, may be used to shorten test times.

VERIFICATION LESSONS LEARNED (A.4.5.1.2.1.2)

A.4.5.1.2.2 Ground and flight aeroacoustic measurements.

Aeroacoustic loads and dynamic response measurements are required for all areas of the airframe designated fatigue critical by analyses of 4.5.1.1 at pertinent operational conditions based on the service life and usage of 3.2.14.

VERIFICATION RATIONALE (4.5.1.2.2)

Since the prediction of noise environments is not sufficiently accurate, measured values must be obtained to revise the environmental estimates and fatigue life predictions. These data also serve as the definition of the environment for the component and full-scale tests of 4.5.1.2.1.

VERIFICATION GUIDANCE (A.4.5.1.2.2)

Measurements of sound pressure levels are needed during flight and ground conditions which produce significant aeroacoustic loads based on the analyses of 4.5.1.1. Sufficient instrumentation is required to measure the loads on the structures which are shown by analysis to be fatigue critical. Internal noise measurements should also be made at this time.

VERIFICATION LESSONS LEARNED (A.4.5.1.2.2)

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Even the best prediction methods are not sufficiently accurate to dispense with measured data. Overestimating the noise environment leads to unnecessary weight and cost; underestimating results in premature failures and maintenance problems.

A.4.5.1.2.3 Jet blast deflector (JBD) acoustic and thermal measurements. (____)

Tests of carrier based airframes are required to measure the airplane acoustic and thermal environment forward and aft of the JBD. The test site shall be free of snow and water. Wind velocity shall not exceed 15 knots, ambient temperature shall not exceed 80°F, and relative humidity shall be between 40 and 80 percent. Measurements shall be accomplished at each of the following test positions and engine power settings.

a. Forward of JBD. The test airplane shall be positioned forward of the JBD in three positions simulating the most critical battery positions which would exist aboard carriers. These positions shall be between 58 feet and 68 feet as measured from catapult station zero to the JBD hinge line. At each of the three positions, all engines of the test airplane shall be stabilized at intermediate thrust for not less than the time required to attain equilibrium structural temperatures, followed by stabilization at maximum thrust for not less than 30 seconds.

b. Aft of JBD. The test airplane shall be positioned aft of the JBD with a second airplane in front of the JBD. The second airplane shall be selected from carrier based qualified aircraft in the inventory such that the airplane/JBD combination shall impart on the test airplane the most critical environment. The test airplane shall be centered immediately behind the JBD with the test airplane centerline perpendicular to the JBD hinge line and separately with the test airplane centerline at a 45 degree angle to the JBD hinge line. For each test airplane position, all second airplane engines shall be stabilized at intermediate thrust for not less than 60 seconds, followed by stabilization at maximum thrust for not less than 30 seconds. All test airplane engines shall operate at idle power during each measurement.

VERIFICATION RATIONALE (A.4.5.1.2.3)

Carrier based aircraft will experience these vibroacoustic and thermal environments prior to and during catapult.

VERIFICATION GUIDANCE (A.4.5.1.2.3)

This requirement is applicable for carrier based aircraft.

VERIFICATION LESSONS LEARNED (A.4.5.1.2.3).

A high performance afterburning fighter in catapult position, produced the highest thermal and acoustic environments on forward portions of aircraft aft of the JBD.

A.3.5.2 Internal noise. (___)

Sound pressure levels in areas of the aircraft occupied by personnel during flight shall be controlled as required by human factors requirements. These shall be __________. Sound treatments shall be integrated with the airframe structure and with airframe subsystems to achieve an optimum balance of weight, cost, and complexity.

REQUIREMENT RATIONALE (A.3.5.2)

Control of interior noise levels is required to prevent hearing damage to personnel and to allow effective communication. Sound treatments added to previously designed structures tend to be

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heavier, more complex, and less successful than those designed in conjunction with the airframe.

REQUIREMENT GUIDANCE (A.3.5.2)

Reference the internal noise level requirements in the blank. References should be to the specific documents, paragraphs, and figures containing these requirements.

REQUIREMENT LESSONS LEARNED (A.3.5.2)

To assure that internal noise levels are at acceptable levels, it is more efficient to require sound transmissions to be in accord with internal noise level requirements at the onset of the program than to rely on costly fixes such as soundproofing after the fuselage structure has been established. In addition to sound transmission through the aircraft surface it must be recognized that internal noise sources such as air conditioning can be significant contributors. Experience with a light ground attack fighter and a swing wing bomber has shown that air conditioning noise is difficult to predict and problems which arise are usually solved by trial and error.

A.4.5.2 Internal noise. (___)

Analyses and tests shall verify that the internal acoustic levels meet the requirements of 3.5.2.

A.4.5.2.1 Analyses.

Internal acoustic levels shall be predicted based on internal noise sources and the near field aeroacoustic predictions of 4.5.1.1 for pertinent operational flight and ground usage defined in 3.2.14.

A.4.5.2.2 Measurements.

Internal acoustic levels shall be measured at personnel stations for pertinent flight conditions as determined by the analyses of 4.5.2.1.

VERIFICATION RATIONALE (A.4.5.2, 4.5.2.1, 4.5.2.2)

Experience on many airplanes has amply demonstrated that prediction of internal noise levels is difficult and inaccurate. A balanced program of analysis, laboratory test, and flight measurements is needed to meet noise criteria.

VERIFICATION GUIDANCE (A.4.5.2, 4.5.2.1, 4.5.2.2)

Develop an internal noise level verification program as needed to assure that the requirements of 3.5.2 are satisfied.

VERIFICATION LESSONS LEARNED (A.4.5.2, 4.5.2.1, 4.5.2.2)

A small propeller driven airplane experienced high cockpit noise levels. Investigation showed the problem was due to vibration of cockpit structures driven by propeller aeroacoustic loading of another portion of the fuselage.

A large, multi engine, propeller driven transport was found to exhibit high noise levels throughout the crew and cargo areas. These levels were found to be due in part to inadequate control of propeller phasing.

A large bomber was found to have high cockpit noise levels. Evaluation of the problem showed that treatment of engine noise and boundary layer noise was adequate but that the air conditioning system was producing the excess noise. Further, it was found to be more efficient

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to provide electronic feedback noise cancellation helmets to the crew rather than to redesign the air conditioning system.

A.3.6 Vibration.

The airframe shall operate in the vibration environments which are commensurate with the required parameters of 3.2, 3.3, 3.4, and rational combinations thereof. Environmental effects such as temperature and humidity shall be included where applicable. Where required, vibration control measures such as damping or isolation shall be incorporated into the air vehicle. There shall be no fatigue cracking or excessive vibration of the airframe structure or components. Excessive vibrations are those structural displacements which result in components of the air vehicle systems not being fully functional. The structure and components shall withstand, without fatigue cracking, the vibrations resulting from all vibration sources for the service life and usage of 3.2.14. Vibration sources include: ________________.

REQUIREMENT RATIONALE (A.3.6)

Determination of sources which must be considered to prevent vibration problems in flight and ground use is needed as a basis of a successful vibration program. A list of generic sources is included below. Other sources should be included as necessary.

Safety and maintenance considerations require that structures and components demonstrate freedom from fatigue cracking for the service life.

MIL-A-8870(ASG), MIL-A-8870B(AS), and MIL-A-8870C(AS) prohibited failures due to vibration and required fail-safe features if failures did occur. MIL-A-8892 required freedom from failures during the service life or the life for replaceable parts.

REQUIREMENT GUIDANCE (A.3.6)

Identify the vibratory sources associated with the air vehicle and its usage. Some sources of vibration to which the airframe may be exposed are listed below.

a. Forces and moments transmitted to the aircraft structure mechanically or aerodynamically from the propulsion systems, secondary power sources, propellers, jet effluxes and aerodynamic wakes, downwashes and vortices (including those from protuberances, speed brakes, wings, flaps, etc.) and cavity resonances.

b. Forces from gun recoil or gun blast.

c. Buffeting forces.

d. Unbalances, both residual and inherent, of rotating components such as propellers, and rotating components of engines.

e. Forces from store and cargo carriage and ejection.

f. Forces due to operation from airfields and ships.

g. Structural response due to gusts.

REQUIREMENT LESSONS LEARNED (A.3.6)

Numerous service problems have resulted because important vibration sources were not considered.

Modification design must account for the effect of changes on the turbulent flow field of the aircraft. Failure to do so can result in structural failures or restriction of the aircraft flight

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envelope. Several aircraft have experienced difficulty with equipment mounted on the vertical tail, such as lights and electronic equipment, because of underestimation of the vibration environment.

On an air superiority fighter, a blade antenna mounted behind the canopy exhibited fatigue failures due to high dynamic loads associated with turbulent flow at high angles of attack. Flight testing of a strengthened blade produced a yield failure of the supporting (backup) structure. Relocation of the antenna to a location not subjected to turbulent airflow resolved the problem.

On an electronic countermeasures aircraft, flight testing showed that blade antennas located downstream from centerline stores were subjected to severe turbulent flow in sideslip maneuvers. Damping material was incorporated into the design of a new antenna to minimize antenna dynamic response loads.

The design of blade antennas and associated mounting structures must account for potentially high dynamic loads, because in-flight separation of an antenna from the aircraft poses risks of downstream damage to the aircraft, injury to ground personnel, and operational deficiencies.

An increase in engine power and a change in propellers was effected without checking empennage response. This resulted in secondary failures in the empennage structure and investigation revealed that primary structure had experienced damage as well. The empennage, it was found, was responding to the propeller slipstream. Solution of the problem consisted of detuning the empennage natural frequencies from the range of propeller excitation frequencies.

Experience with doors and access panels demonstrates that careful attention should be given to the effects of buffeting and movement in flight.

A.4.6 Vibration.

Analyses and tests shall verify that the airframe can operate in the vibration environments of operational use as required by 3.6.

A.4.6.1 Analyses.

Vibration levels shall be predicted for the airframe and components based on the sources of 3.6 and the service life and usage of 3.2.14.

VERIFICATION RATIONALE (A.4.6.1)

Estimates of vibration environments are needed to support structural design and test requirements, as the basis for requirements in equipment procurements, and to determine the necessity for and means of vibration control measures. This need was recognized in MIL-A-8870(ASG), MIL-A-8892, and MIL-STD-1530.

VERIFICATION GUIDANCE (A.4.6.1)

Perform analyses to predict vibration levels for the airframe using existing data bases. These analyses should be performed early in the development process and revised as measured vibration and acoustic data are obtained.

VERIFICATION LESSONS LEARNED (A.4.6.1)

It is necessary in most procurements that subcontractors be on contract before environmental measurements are available in order to meet delivery schedules. Structural response predictions are frequently inadequate due to uncertainties in the critical parameters and

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inaccuracies in the analytical models used in the prediction process. Inadequate or inaccurate vibration predictions result in both under and over design, retest, and retrofit.

In a bomber aircraft program, extensive redesign of equipment mounting structure was needed to reduce the vibration levels to the equipment. The equipment had been designed and built to meet an environment that was much less severe than was actually experienced.

A.4.6.2 Tests.

A.4.6.2.1 Development tests.

Development tests are required for structures which cannot be adequately analyzed.

VERIFICATION RATIONALE (A.4.6.2.1)

Component tests are needed to verify analytical fatigue life predictions and demonstrate that the components will meet service usage requirements in the vibration environment. In many cases, analyses are not sufficiently accurate to risk proceeding directly to production without some testing. This requirement is contained in MIL-A-8870(ASG), MIL-A-8892, MIL-A-8870B(AS), and MIL-A-8870C(AS).

VERIFICATION GUIDANCE (A.4.6.2.1)

Tests should be performed on safety-of-flight structural components and candidate structures where basic data such as S-N curves, fatigue data, or experience with the structural configurations do not exist.

VERIFICATION LESSONS LEARNED (A.4.6.2.1)

Experience has shown that analyses alone are not sufficiently accurate to verify fatigue resistant structure.

A.4.6.2.2 Ground vibration tests.

Ground vibration tests of a complete airframe in accordance with 4.7.d(1) shall include determination of natural frequencies, mode shapes, and damping of vibration of airframe components supportive of the requirements of 3.5 and 3.6.

VERIFICATION RATIONALE (A.4.6.2.2)

This test effort provides the vibration modal characteristics of the airframe and its components. The requirement was derived from MIL-A-8870(ASG), MIL-A-008870A(USAF), MIL-A-8892, MIL-A-8870B(AS), and MIL-A-8870C(AS).

VERIFICATION GUIDANCE (A.4.6.2.2)

Measurements need to be obtained as early as possible to allow making any needed changes and keep retrofits to a minimum. These tests are to be coordinated with the ground vibration tests of 4.7.d.(1).

Propulsion system. Mode shapes and frequencies of power plant (engine and gearbox) installations should be obtained when (1) these components are supported by resilient mountings (vibrations or shock isolators), (2) unit flexible modes are low enough in frequency to couple with airframe flexible modes, or (3) separate units are coupled by shafting (turbine driving a propeller gearrbox, engine driving a propeller through an extended shaft, power takeoff shaft driving a separate machine or gearbox, etc). Natural frequencies and mode shapes of the sprung mass of each unit should be obtained for the six fundamental rigid body

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modes of motion (three translational and three rotational modes). These data should also be acquired for the coupled system as well as for each unit. Where multiple units are mounted in significantly different locations (inboard and outboard on a wing, wing and aft fuselage, etc.), acquire the data for each location.

Identify other components for which frequency and mode data measurements are needed such as weapon bay doors, wheel well doors, etc.

VERIFICATION LESSONS LEARNED (A.4.6.2.2)

One of the resonances of the weapon bay doors of a large aircraft coincided with a cavity resonance, causing large amplitude motions of the doors when the weapon bay was opened in flight. A vibration test of these doors was not done and, hence, the problem not detected until flight tests.

During ground vibration test of a large transport aircraft, it was discovered that the first horizontal tail pitch mode, an internal resonance in a pitch stability augmentation system component, and a resonance of the shelf on which the component was mounted were all at the same frequency. The result was that once the tail pitch mode was excited the vibration was self sustaining. This would probably have resulted in violent and dangerous oscillations in flight. The problem was eliminated prior to first flight by detuning the shelf and component resonances.

A.4.6.2.3 Ground and flight vibration measurements.

Ground and flight vibration measurements shall be conducted to verify and correct predicted vibration levels, and demonstrate that there are no excessive vibrations. Measurements shall be made at a sufficient number of locations to define the vibration characteristics of the airframe and for flight and ground operating conditions in accordance with the service life and usage of 3.2.14.

VERIFICATION RATIONALE (A.4.6.2.3)

Ground and flight vibration tests are used to obtain the response characteristics of the aircraft to forced vibrations and impulses. Test results either verify or are used to correct analytical predictions of the vibration environment, serve as the basis to verify the analytical and test vibratory fatigue lives, and also as the basis of equipment environmental requirements. The need for or effectiveness of vibration control measures will also be determined. This requirement was a part of MIL-A-8870(ASG), MIL-A-8892, MIL-A-8870B(AS), and MIL-A-8870C(AS).

VERIFICATION GUIDANCE (A.4.6.2.3)

Measurements are needed during flight and ground conditions to define vibrations of the airframe. Sufficient instrumentation is required to define the responses of the structure and equipment. The measurement programs are to be coordinated with similar efforts of 4.5 and 4.7.

Ground and flight vibration tests should include ground engine runup to maximum thrust, taxi, takeoff, climb, level flight with at least five speed increments at two altitudes, approach glide, and landing. The flight altitudes and speeds should be selected to include normal cruise conditions, maximum permissible transonic flight dynamic pressure, maximum dynamic pressure at maximum Mach number, and maximum dynamic pressure as applicable to each of the following listed flight operations, conditions, and maneuvers.

a. Operating afterburners with and without any takeoff assist units.

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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.

g. Deflecting speed brakes.

h. Lowering landing gears 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 at maximum permissible load factor and critical store combinations.

k. During maneuvers at intermediate and maximum permissible symmetrical and unsymmetrical load factors.

l. At flight conditions consistent with the mission profiles of 3.2.14 where buffet is predicted.

A sufficient number of transducers should be utilized to define adequately the vibration characteristics of the airplane. Transducers should be so mounted that the transducer and mounting bracket or block will not significantly alter the response characteristics of the item under consideration. Normally, the airplane will be divided into zones (e.g., nose, center, and aft fuselage; outer and inner wing; empennage; landing gear cavity; engine compartments; and nacelles and pylons). Measurements should be made at several locations in each zone. Emphasis should be placed on locations where high amplitudes of vibration are expected or where failures could be critical with respect to flight safety. Measurements should include, but not be limited to, the following locations:

a. Electronic and mechanical equipment areas.

b. Areas where a failure or malfunction might result in loss of or significant damage to the air vehicle.

c. Fuselage sidewall in the region of propellers.

d. Passenger and cargo compartments.

e. Mounts, bearing supports and gear boxes at engines, transmissions, rotating mechanical equipment, and drive shafts.

f. Cavities.

g. Gun locations. Equipment and structure located within a minimum radius of 6 feet of the gun mountings and muzzles should be instrumented. Wherever possible, vibration transducers should be internally mounted in surrounding equipment (particularly shock mounted equipment). Equipment mounting point vibration should be recorded.

h. Inlets.

i. On external stores and structures near ejectable stores.

j. Crew and passenger seats (longitudinal, lateral, and vertical).

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k. Rudder pedal (longitudinal).

l. Rudder heel troughs (vertical).

m. Handle at terminal of primary flight control system (longitudinal and lateral).

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

o. Primary longitudinal structural members in fuselage (vertical and lateral at the approximate position of crew seat attachment points).

p. Wing and horizontal stabilizer tips (vertical and longitudinal, and vertical stabilizer tips, lateral and longitudinal).

q. Balance weights: Normal and the other two mutually perpendicular directions of control surfaces and tabs. (See 3.7.1.1 for design criteria.)

VERIFICATION LESSONS LEARNED (A.4.6.2.3)

Analyses are not complete or accurate enough to provide the information to define vibration responses to the degree necessary. Experience has shown that many problems arise in flight that were not suspected or adequately scoped previously.

Some programs profited from instrumented missiles devoted solely to measuring vibration, loads, temperatures, and aeroacoustic loads.

A.3.7 Aeroelasticity.

The airframe shall operate in the flight environment which is commensurate with the general parameters of 3.2 and the failures of 3.7.3. The airframe shall meet the following requirements to preclude any aeroelastic related phenomena from degrading the required operational and maintenance capability of the airframe.

REQUIREMENT RATIONALE (3.7)

The purpose of this requirement is to insure that the air vehicle and its components shall have adequate airspeed and damping margins of safety to prevent flutter, buzz, divergence or other dynamic aeroelastic, aerothermoelastic or aeroservoelastic instabilities within the air vehicle's flight environment. This requirement shall apply throughout the design range of altitudes, speeds, maneuvers, weights, fuel content, thermal conditions, external store configurations, any design loading condition where loss of rigidity is significant, and other loading conditions (such as flap schedules, hydraulic pressure states, or any other changeable aircraft system or component that could affect aeroelastic stability).

REQUIREMENT GUIDANCE (A.3.7)

This requirement always applies.

REQUIREMENT LESSONS LEARNED (3.7)

All classes of air vehicles have experienced flutter or buzz incidents which required redesign of structure, redesign of a portion of the control systems, extended development testing, or resulted in late deliveries or operational restrictions. For some configurations and conditions, flutter can involve safety of flight with extremely rapid catastrophic structural damage and possible loss of the vehicle.

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A.4.7 Aeroelasticity.

Analyses and tests shall verify that the air vehicle can operate in the flight environment associated with the operational use as required by the aeroelastic stability requirements of 3.7.

VERIFICATION RATIONALE (4.7)

A comprehensive aeroelastic stability program is necessary to demonstrate compliance with the requirements of 3.7. This program should include analyses, wind tunnel flutter model tests, ground vibration tests, flight flutter tests, and other tests (such as freeplay and rigidity of control surfaces) as required. The analyses should consider ranges of important parameters and use aerodynamics commensurate with the aircraft's flight environment. Appropriate test results should be used to update and validate these analyses. Aeroelastic stability analyses are required for proposed aircraft modifications when those modifications may in any way affect the aeroelastic stability of the air vehicle.

VERIFICATION GUIDANCE (4.7)

This requirement always applies.

VERIFICATION LESSONS LEARNED (4.7)

Past experiences have shown that a comprehensive and well planned aeroelastic stability program consisting of analyses and tests will ensure adequate design criteria, thereby minimizing the possibility of unexpected and costly design changes.

a. Analyses.

(1) Basic air vehicle flutter analyses. (___).

VERIFICATION RATIONALE (4.7.a(1))

Flutter analyses are required to provide verification of the air vehicle design (including structural stiffness distribution, mass distribution, fuel distribution, fuel management, and automatic flight control characteristics) to satisfy the airspeed and damping margins of safety for all design conditions. These analyses are also essential to:

a. Guide configuration selection for flutter model, ground vibration, and flight flutter test programs.

b. Predict modal frequency and damping of the primary modes of interest of a given air vehicle configuration prior to flight flutter testing.

c. Establish air vehicle's flutter clearance (in conjunction with the ground and flight test results).

d. Provide information regarding the feasibility of design changes and to demonstrate proof of design.

VERIFICATION GUIDANCE (4.7.a(1))

These analyses are required if the air vehicle is a new air vehicle or if changes occur which affect the flutter characteristics of an existing air vehicle.

The flutter analyses should be conducted for the complete air vehicle. However, component (such as wing, wing and fuselage, horizontal tail, vertical tail, etc.) flutter analyses are necessary in the preliminary design stage. Component attachment stiffness, control surface circuit stiffness and freeplay, control surface mass balance, fuel quantity, and loading conditions are some important design parameters to be evaluated. Analyses formulated to show the sensitivity of the flutter characteristics to such parameters are useful for evaluating

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critical design areas, fail-safe design criteria and the consequence of service related changes. The complete air vehicle flutter analyses may be based on either a semi-span or full-span dynamic mathematical model. In the semi-span dynamic model formulation, both symmetric and antisymmetric boundary conditions and corresponding modes should be investigated in the flutter analyses.

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

Critical flutter mechanisms should be identified and investigated. Predicted flutter boundaries (such as flutter speed versus Mach number) should be defined for these mechanisms. Matched-point flutter analyses should be performed to determine the flutter boundaries for the various critical flutter mechanisms. A matched-point flutter condition is obtained when the flutter speed, air density, and Mach number are consistent for a standard atmospheric condition.

Normal design and fail-safe design cases should be investigated. 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) should be varied to cover the expected range.

Analyses should use aerodynamic formulations based on theories recognized as being applicable to the specified operating Mach number range. In the transonic range, corrections to theory are required based on oscillatory aerodynamics measured during wind tunnel tests, flutter model wind tunnel tests, or weighing factors based on static wind tunnel model test data. Validation of subsonic, transonic, and supersonic analyses methods is recommended by comparing results with corresponding test results. Unsteady aerodynamic force prediction methods used in the air vehicle flutter analyses are validated/calibrated as a result of flutter model wind tunnel tests. The use of the subsonic and transonic flutter models are especially appropriate for designs structurally and aerodynamically complicated by elastically suspended engines and external stores.

The analysis should be updated as necessary using the available aerodynamic characteristics as determined from wind tunnel tests, structural data, control system data, ground vibration test data, and other data as appropriate.

The effects of transient and steady-state heating should be included in all analyses as appropriate.

VERIFICATION LESSONS LEARNED (4.7.a(1))

It is not uncommon for the design of main components of an air vehicle to be significantly affected by flutter requirements. These requirements have often affected stiffness distributions, mass distributions, the placement of podded engines, the location of external store supporting points, fuel tank arrangement, fuel management, stiffness requirements of pylons supporting engines and external stores, circuit stiffness of all-movable-surfaces, control surface arrangement, and planform geometry.

Test results obtained during envelope expansion of several large multi-engine aircraft have shown the necessity of installing wing tip weights, installing engine pod weights, modifying the fuel schedule, or repositioning engine pods in order to prevent primary lifting surface flutter.

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Other cases involving fighter aircraft, as a result of flight experience, have required the reduction of the horizontal stabilizer surface area or a modification of the horizontal stabilizer mass balance.

(2) Control surface, tab, and other component flutter analyses. (___) These analyses shall be conducted for normal and failure conditions. For circuit stiffness designed control surfaces, tabs and other movable components, free play limits and maximum allowable inertial properties shall be determined and established in maintenance manuals. Techniques and procedures shall be developed for free play inspection and maintenance at field and depot levels. In addition, maintenance plans and manuals must include a process for checking and adjusting mass balance after surface repair or painting.

VERIFICATION RATIONALE (4.7.a(2))

Control surface or tab flutter is possible at all flying speeds and historically has been the most common type of flutter. Analyses are necessary to establish mass balance and stiffness requirements and for design substantiation. These analyses should be done as part of the basic air vehicle design substantiation.

VERIFICATION GUIDANCE (4.7.a(2))

These analyses are required if the air vehicle is a new air vehicle or if changes occur which affect the control system or tab flutter characteristics of an existing air vehicle.

Prevention of control surface flutter is effected by mass balance, actuator stiffness, free-play, damping and spanwise location. Analytical evaluation of all possible failure conditions involving actuators, dampers, and maintenance oversights are essential. Care must be taken in relying upon theoretical control surface coefficients. These coefficients are function of Mach number, often are nonlinear, and should be weighted using static wind tunnel data. Considering the effect of aerodynamic overbalance is important as is the effect of seals.

For all-movable-surface flutter analyses, both symmetric and antisymmetric modes should be investigated. All modes contributing to an all-movable-surface flutter mechanism should be included in the flutter analyses. Such modes normally include first and second bending, rotation, and torsion modes. Where the axis of rotation is not in the plane of the surface, the fore-and-aft motion of the surface should also be included. The rotational frequency of the surface should be varied over the ranges to cover both normal and failure operations.

The rotational frequencies of all control surfaces and tabs in the flutter analyses should be varied over the range to cover both normal and failure conditions. The control-surface flexibility should be included in the analyses to establish its importance.

Flutter analyses should be made for all spring tabs, regardless of the limit speed of the airplane and even though mass balance is employed. The flutter analyses should include spring tab, control surface, main fixed supporting surface, and control-system modes. The effective inertia of the control column or pedals should be varied to cover the probable range.

Flutter investigations should be performed on airplane components, other than control surfaces, which are exposed to the airstream such as leading edge flaps, trailing edge flaps, spoilers, dive brakes, canard surfaces, scoops, weapon bay doors, landing gear doors, ventral fins (fixed, retractable, or jettisonable), movable fairings, blade antennas, and blade seals.

Parametric variation flutter analyses should be performed to determine the sensitivity of the airspeed and damping 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

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studies, the maximum structural repair mass properties (including the effects of structural repairs and paint) allowable, without degradation in margins of safety, shall be established.

VERIFICATION LESSONS LEARNED (4.7.a(2))

A reconnaissance aircraft encountered two higher order, wing-aileron flutter mechanisms during operational use and subsequent flight testing. Analyses, ground vibration, and flight tests were accomplished to validate additional distributed aileron mass balance and a slight decrease in the limit speed operating envelope.

Most of an all-movable fin on an attack aircraft was lost to flutter during flight testing. Analyses, ground vibration, and a flight test program verified that stiffening of the fin control spindle and a new composite fin provided adequate stability.

Fin-rudder flutter was experienced twice, and parts lost, during flight flutter testing of a large communications aircraft. Extensive analyses, ground and flight tests demonstrated the stability of the fixes involving fin structural and rudder hydraulic system modifications.

A trainer aircraft encountered aileron-wing flutter during flight flutter testing. Analyses and flight tests verified additional aileron mass balance was required.

An attack airplane undergoing developing flight tests, but subsequent to several months of operational flying, encountered elevator flutter following a sharp control actuator induced transient. Careful analyses, using remeasured horizontal stabilizer modal test data, showed that a modification of the elevator mass balance would provide stability.

An observation airplane encountered elevator tab flutter following introduction into operational use.

A small attack airplane encountered rudder-fin coupled flutter during development testing. Mass balance failed as a fix. Prevention was effected by modifying the rudder geometry. The incident placed an interim operational speed restriction upon the airplane and delayed the delivery.

(3) Divergence analyses. (___).

VERIFICATION RATIONALE (4.7.a(3))

Divergence is a static aeroelastic phenomena which causes structural failure at the critical speed or above. Sufficiently swept back surfaces are not susceptible to divergence. Examples of lifting surfaces (swept forward, straight, or moderately swept back) and bodies requiring divergence verification are wings, wings with tip stores, landing gear doors, weapons bay doors, forward positioned engines, external stores, leading edge flaps, all-movable control surfaces and their actuating systems, and the leading edges of surfaces.

VERIFICATION GUIDANCE (4.7.a(3))

These analyses are required if the air vehicle is a new air vehicle or if changes occur which affect the divergence characteristics of an existing air vehicle.

Divergence analyses should be performed for wings, horizontal and vertical stabilizers, leading edge flaps, all-movable control surfaces and their actuating systems, and the leading edges of surfaces. In addition, the following shall apply:

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

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

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

VERIFICATION LESSONS LEARNED (4.7.a(3))

A drop-out generator was installed and retrofitted to a number of small attack aircraft. Loss of the generator during tests led to a reevaluation of the structural analysis which showed ample strength margin; however, a flutter analysis showed a rapid frequency reduction indicating divergence in the torsion mode.

A fighter experienced several incidents of lost landing gear doors. Investigation showed that during accelerated maneuvers the door gapped resulting in structural divergence.

Also see Lessons Learned under 3.7.1.2.

(4) Buzz analyses. (___).

VERIFICATION RATIONALE (4.7.a(4))

Buzz jeopardizes the structural integrity of control surfaces and reduces the service life of control surface actuators, hinges, and bearings.

VERIFICATION GUIDANCE (4.7.a(4))

These analyses are required if 3.7.1.3 is applicable and if the air vehicle is a new air vehicle or if changes occur which affect buzz characteristics of an existing air vehicle.

There are no generally accepted methods for analytically predicting the speed and frequency at which control surface buzz occurs. Although progress is being made in buzz predictions using Computational Fluid Dynamics (CFD) techniques, empirical design criteria based on a minimum reduced frequency for the control surface in the transonic regime is normally used if the control surface's motion influences the alternating upper surface and lower surface shock formations (see Lessons Learned of 3.7.1.3).

VERIFICATION LESSONS LEARNED (4.7.a(4))

There have been many occurrences of control surface buzz which required a corrective design following initial flight tests. Some examples are as follows: A fighter aileron required the addition of ten percent critical damping to prevent buzz; but the rudder, having about 40 degrees of sweep, was buzz free without dampers. A small attack aircraft experienced antisymmetric elevator buzz which was corrected by replacing the aluminum cross tie with steel.

Buzz can be prevented by the use of control surface dampers, actuator and backup rigidity (circuit stiffness), aerodynamic modifications, or shock stabilizing strips on the surface where the shock wave occurs.

(5) Airplane with external store flutter analyses. (___) Stores shall be put into inertia and aerodynamic properties classes for the range of required store loadings such as to minimize the total airplane with external stores analyses effort. Sway brace preloads shall be defined and established in appropriate user manuals.

VERIFICATION RATIONALE (4.7.a(5))

Detailed flutter analyses for the airplane with external stores have been found to be important in an overall store flutter clearance program. The analyses serve as a baseline and parameter sensitivity indicator for planning the flutter model wind tunnel and flutter flight test programs.

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Control of sway brace preload by appropriate maintenance manual instructions gives some assurance that the design rigidity for flutter prevention is maintained.

VERIFICATION GUIDANCE (4.7.a(5))

These analyses are required if 3.7.1.4 is applicable and if the air vehicle is a new air vehicle or if changes occur which affect the flutter characteristics of an existing air vehicle.

For analyses requiring a broad range of store loadings, the analyses should identify the critical flutter parameters. These results should be used as a basis for determining the extent of additional flutter analyses required when modification or addition to the store list, racks, pylons, sway braces, or external fuel tanks are specified.

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, should be included in the analyses. Analyses for external fuel tanks should include the half-full forward and half-full aft center of gravity conditions in addition to the empty and full fuel conditions.

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

Full span aircraft flutter analyses should be used to investigate and identify the flutter characteristics of various asymmetric store loadings.

VERIFICATION LESSONS LEARNED (4.7.a(5))

The parameters which affect external store flutter must be examined carefully to insure their flutter sensitivity is well understood. Too early reliance on trend data and unwarranted extrapolation or interpolation of flutter results can lead to omission of analytical flutter solutions which could produce flutter velocities well below the required velocity margin.

For example, in the case of an attack aircraft flutter analysis program which required flutter clearance for a wide variety of stores and store locations, it was found that one parameter (store chordwise location) produced a light to moderate effect on flutter velocity over most of its range but a severe effect over a very small portion of its range. This erratic behavior in this case was traced to a change in the character of the flutter mode for a small movement of the store location.

Manufacturing and installation tolerances should be considered when the external store flutter sensitivity studies are conducted. The previously mentioned discontinuous behavior of some external store flutter solutions has implications on such items as sway-brace preloads, store center-of-gravity locations, fuel tank contents and store external geometry. For example, field measurements of as-installed store c.g., locations may vary as much as +/-2 percent of the wing chord from handbook specified values.

Parametric flutter analysis involving aircraft carriage of external stores can be an effective approach in the stores clearance program. SEG-TR-67-2 documents a case of a successful parametric flutter analysis program.

Underwing external store aerodynamics are not generally included in wing/store flutter analyses unless the stores are unusually large or have large aerodynamic fins. However, wings with tip stores should include tip store aerodynamics. The following cases illustrate that flutter of wings

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with tip tanks can be very catastrophic with severe consequences and shows the need to include tip store aerodynamics. On 10 July 1950, there was a serious flutter accident on a jet fighter equipped with tip tanks. On 17 May 1976, a similar airplane with different tip store but with similar aft center-of-gravity location experienced a similar type flutter accident. The stores were torn off the wings very rapidly with serious fractures of the wing main spar, controls, and other structure, although the aircraft was safely landed. Results of analyses with and without tip store aerodynamics and comparison with flight flutter data are presented on figures 18 and 19.

Store flutter analyses should make use of experimental aerodynamic data, if available. Unsteady aerodynamic data on a wing with several stores are presented in AFFDL-TR-78-194 and used for flutter evaluation in AIAA Paper 81-0606. A wind tunnel correlation study of aerodynamic modeling for a fighter with stores is presented in AIAA Paper 83-1028.

(6) Panel flutter analyses. (___).

VERIFICATION RATIONALE (4.7.a(6))

Panel flutter occurs on improperly stiffened panels exposed to supersonic flow. The possibility of panel flutter is increased by insufficient stiffening in-line with the flow, inplane compression loading, and flat surfaces. Developing design criteria and showing proof of design requires the use of theoretically developed nondimensional parameters enhanced by empirical data.

VERIFICATION GUIDANCE (4.7.a(6))

These analyses are required if 3.7.1.5 is applicable and if the air vehicle is a new air vehicle or if changes occur which affect the panel flutter characteristics of an existing air vehicle.

Evaluations based on existing panel flutter design criteria should 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 may be subjected to in-plane compressive stresses either due to aircraft maneuvering or aerodynamic heating, a buckled or near buckled condition, whichever is most critical, should be assumed unless an accurate prediction of the compressive stresses and their effects on panel flutter can be made. The aerodynamic conditions used should be the local conditions existing at the panel surface which may be altered from the free stream by airplane attitude or surface shape.

AFFDL-TR-67-140 provides one source of design criteria for the prediction and prevention of panel flutter.

VERIFICATION LESSONS LEARNED (4.7.a(6))

Low aspect ratio, AR < 0.2, sheet aluminum panels on a wide bodied transport exposed to supersonic turbofan bypass flow exhibited short service life due to fatigue cracks. Subsequently, the cracks were attributed to panel flutter. A panel flutter evaluation had not been conducted during the design phase. Many other panel flutter incidents experienced on flight vehicles and associated test data are documented in ARTC-32 and AGARD Advisory Report 1.

(7) Whirl flutter analyses. (___).

VERIFICATION RATIONALE (4.7.a(7))

Analyses are required to demonstrate freedom from whirl flutter for the basic design and to establish the design criteria for the power plant installation with respect to structural stiffness and with respect to structural redundancy as needed to allow for single member failures.

The principal concern is to provide sufficient structural redundancy such that rigidity loss or vibration mode shape change resulting from failure of any structural element supporting the

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propeller or fan will not precipitate a whirl instability. Ducted fans are less prone to whirl flutter as compared to free fans. Because of the uncertainty in predicting unsteady aerodynamic coefficients, consideration should be given to validating the analysis of large propeller installations with aeroelastic model tests.

VERIFICATION GUIDANCE (4.7.a(7))

These analyses are required if 3.7.1.7 is applicable and if the air vehicle is a new air vehicle or if changes occur which affect the whirl flutter characteristics of an existing air vehicle.

Whirl instability of propeller-engine systems should be analyzed. All important modes should be included in the analyses, such as the pylon pitch-and-yaw and aircraft rigid and flexible modes. For propeller or large turbofan-driven airplanes, the blade aerodynamics, blade flexibility, powerplant flexibilities, powerplant mounting characteristics, and gyroscopic effects should be included in the flutter analyses where these effects are significant.

VERIFICATION LESSONS LEARNED (4.7.a(7))

A turboprop transport experienced destructive wing flutter resulting from propeller whirl coupling. Investigation indicated that the incident was precipitated by failure of a structural member connecting the propeller-gear-box assembly to the compressor. Redundant structural members were added to prevent recurrence of the flutter.

(8) Aeroservoelastic stability analyses. (___).

VERIFICATION RATIONALE (4.7.a(8))

Analyses and tests have shown that the automatic flight control system must be designed such that unfavorable coupling with the flexible structure will not cause an aeroservoelastic instability.

VERIFICATION GUIDANCE (4.7.a(8))

These analyses are required if the new air vehicle has a flight control augmentation system or if changes occur which affect the aeroservoelastic stability characteristics of an existing air vehicle.

The analyses should be conducted for the critical flight conditions, taking into account the flight control systems gain scheduling and control surface effectiveness. The analysis should be updated as necessary using the available aerodynamic characteristics as determined from wind tunnel tests, structural data, control system data, ground vibration test data including flight control sensor response data, and other data as appropriate.

The mathematical representation of the structural/control system should be verified by correlating the analysis with aeroservoelastic ground tests (open loop frequency response).

VERIFICATION LESSONS LEARNED (A.4.7.a(8))

Analyses and subsequent ground vibration tests of a transport airplane showed unstable elastic modal coupling in the roll axis and in the longitudinal axis. Based upon an examination of the elastic vibratory modes it was clear that sensor relocation would be a solution; however, relocation was not practical because of accessibility requirements for maintenance. The instability gain was stabilized by using notch filters.

Aeroservoelastic (ASE) instabilities were encountered on two lightweight fighters. In spite of limited ASE analyses conducted, the aircraft experienced two separate ASE instabilities during early flight tests. The ASE analyses were conducted at a high Mach number (M = 1.2), low altitude flight condition, which was the most critical for classical flutter. However, based on control system effectiveness variations within the operating envelope, the most critical interaction occurred in the high subsonic Mach number (M = 0.9) regime, which was not an

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analysis condition. Later ASE analyses at the proper flight condition did correlate with the flight test results. These two ASE instabilities were eliminated by adding a notch filter and reducing the gain in the roll channel feedback loop of the flight control system. Similarly, another fighter had two potential aeroservoelastic instabilities. These instabilities were predicted. Parametric aeroservoelastic analyses of ground test and flight test interactions were done to select the final notch filters for the flight control system.

b. Wind tunnel model tests.

(1) Low speed flutter model tests. (___).

VERIFICATION RATIONALE (4.7.b(1))

Low speed wind tunnel testing is a useful tool to substantiate the flutter characteristics associated with the numerous design changes that occur early in a program. Such testing also validates the methods used in the flutter analyses.

VERIFICATION GUIDANCE (4.7.b(1))

These tests may be required early in the design stage to provide initial substantiation of the flutter margins of 3.7.1a, the analyses of 4.7.a, and the flutter analyses used to perform parameter variation investigations.

These tests should be performed for a sufficient range of variables covering the flight envelope and a complete range of weights and required external store loadings and conditions, including partially released or hung stores. The investigation should include the important flutter parameters of the wing, fuselage, empennage, and control surfaces. Where the flutter speeds are sensitive to variations in one or more parameters, the critical parameter(s) should be varied to cover the expected range.

It should be demonstrated by suitable analyses and tests that the flutter models dynamically simulate as near as practical the full scale airplane. As a minimum, flutter analyses of the flutter models themselves should be performed for correlation with tunnel test results; thus, verifying the analytic methods used to predict the flutter characteristics of the actual aircraft. For the case of design verification model tests, if it is determined by analysis, static tests, or vibration tests that significant discrepancies exist between the flutter parameters of the models and the airplane, additional tests on suitably modified models should be performed.

VERIFICATION LESSONS LEARNED (A.4.7.b(1))

RTD-TDR-63-4197 and NASA SP-415 document representative cases of low speed flutter model design and tests.

(2) High speed flutter model tests. (___).

VERIFICATION RATIONALE (4.7.b(2))

Linear analytical flutter techniques have doubtful validity in the transonic regime. Transonic model testing is the only way to validate an air vehicle's transonic flutter characteristics prior to flight flutter testing.

Transonic and/or supersonic flutter model testing is a useful tool to substantiate the air vehicle's design flutter characteristics and flutter airspeed margins in the transonic and/or supersonic regimes. Alternately, testing of representative models of the air vehicle configuration can be used to validate and calibrate the flutter analyses methods and transonic and supersonic unsteady aerodynamics used in the air vehicle flutter analyses.

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VERIFICATION GUIDANCE (4.7.b(2))

These tests are required if the air vehicle is a new air vehicle or if changes occur which significantly affect the flutter characteristics of an existing vehicle and if the vehicle's flight envelope includes the transonic or supersonic regime and if the minimum flutter speed margins are predicted to occur in these regimes.

As a general rule, transonic flutter models have been used when the V_L is greater than 0.7 Mach number. Also see Guidance under 4.7.b(1).

VERIFICATION LESSONS LEARNED (4.7.b(2))

During the development program of an air superiority fighter, analysis and low speed flutter model tests of the horizontal tail design had shown freedom from flutter including just meeting the required flutter speed margin. However, during transonic model testing, the design was shown to have deficient flutter speed margin in the transonic flight regime. This necessitated a horizontal tail redesign late in the development program. This redesign effort included empennage component transonic flutter model testing to validate the redesign. This effort occurred shortly before flight testing began.

The torsional stiffness of the vertical tail of the T-tail design of a very large transport aircraft was increased as a result of transonic flutter model tests.

During the development program of a fighter, transonic flutter model tests of the complete airplane with and without wing mounted external stores were an integral part of the flutter program. These tests were used to show margins and define flutter speed boundaries of critical configurations. For example, one tunnel entry of the model with an increased area horizontal tail design was conducted to investigate potential design alternatives and a later entry to validate the flutter speed margin of the final design before flight testing began.

During the development of a large transport airplane, a transonic flutter model test was conducted of several configurations of a scaled component wing model which included a supercritical airfoil, winglets, and large flexibly mounted engine nacelles. The primary purpose of the test was to provide a basis for verifying or improving analyses methods used in substantiating the flutter stability of the final airplane design. This test is documented in NASA-TM-87753.

In an air superiority fighter development program, supersonic and transonic component flutter model tests were conducted. The primary test objective was to validate and calibrate flutter analyses methods and aerodynamics used on the airplane in the supersonic and transonic regimes. Cantilever surface models were tested that were representative of the airplane configuration. A large number of flutter points were obtained and trends on the major surfaces were confirmed.

RTD-TDR-63-4197 and NASA SP-415 document representative cases of high speed flutter model design and tests.

(3) Unsteady pressure measurements. (___).

VERIFICATION RATIONALE (4.7.b(3))

Analytical flutter techniques have doubtful validity in the transonic regime. Unsteady pressure model measurements can be used to understand the physics of transonic aerodynamic flows and the test results can be used to validate and update the methods used in the analysis predictions.

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VERIFICATION GUIDANCE (4.7.b(3))

These tests can be used to supplement high speed flutter model tests.

VERIFICATION LESSONS LEARNED (4.7.b(3))

An unsteady pressure model test was conducted of a semi-span wing body configuration with wing stores of a fighter aircraft. Test objectives were (1) to understand the physics of unsteady transonic flows typical of full-scale limit cycle oscillation (LCO) on fighter type wings and (2) develop an unsteady aerodynamic data base for use in LCO semi-empirical prediction method development. These objectives were achieved.

AFWAL-TM-80-1-FIBR, AFFDL-TR-78-194, AFWAL-TR-83-3039, WL-TR-94-3017, WL-TR-94-3094, WL-TR-94-3095, and WL-TR-94-3096 document some cases of unsteady aerodynamic testing.

c. Laboratory tests.

(1) Component ground vibration tests. (___).

VERIFICATION RATIONALE (4.7.c(1))

These tests are required as necessary, to validate the analyses of 4.7.a. Items to be tested include main air vehicle components, such as external store pylons, engine pylons, pylon with external fuel tanks in various fuel loadings, launchers and racks with representative store loading, and other critical components.

Ground vibration tests of critical components can often be used to check criteria compliance at a stage in the program sufficiently early to permit corrective action without seriously jeopardizing the overall program schedule.

VERIFICATION GUIDANCE (4.7.c(1))

If these tests are required, define or list the tests required in the blank.

Vibration modal characteristics, i.e., resonant frequencies, mode shapes, and structural damping should be measured, if practical on key components prior to vehicle assembly. Components which may fall into this category are control surfaces, pylons, flaps, horizontal stabilizers, control surface actuators, control surface dampers and racks for supporting external stores. Often these tests can be combined with other tests, e.g., the control simulator test or the structural loads tests. Control surface damper compliance tests require a special set-up and must be carefully conducted under laboratory conditions.

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

VERIFICATION LESSONS LEARNED (4.7.c(1))

In the case of an attack aircraft with a multitude of pylon-rack-store combinations, component vibration tests were performed to derive the flexibility influence coefficient matrices. The flexibility matrix was extracted from the modal data by the following technique:

The equations of linear free vibration were written for the six degree of freedom system. The measured modal matrix, which was made orthonormal on the mass matrix, and the diagonal frequency squared matrix were substituted in the equations to obtain an expression for the stiffness matrix. The inversion of this expression yielded an equation for the flexibility matrix in terms of the measured orthonormal modal matrix and the frequency-squared inverse matrix.

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Although the general application of this method required an iterative process to arrive at a final refined flexibility matrix, it did yield a satisfactory measurement of flexibility.

(2) Mass measurements of control surfaces and tabs. (___).

VERIFICATION RATIONALE (4.7.c(2))

These tests are required to validate the analysis of 4.7.a(2).

VERIFICATION GUIDANCE (4.7.c(2))

These tests are required if 3.7.1.1 is applicable and if the air vehicle is a new air vehicle or if changes in the design or manufacturing processes of the surfaces or tabs occur.

The total weight, static unbalance, and mass moment of inertia about the hinge line of all control surfaces, tabs, leading and trailing edge flaps should be measured. These tests should be made prior to first flight of a new air vehicle or prior to flight when changes to the surface or tabs occur.

VERIFICATION LESSONS LEARNED (4.7.c(2))

(3) Control surface, tab, and actuator rigidity, free play, and wear tests. (___).

VERIFICATION RATIONALE (4.7.c(3))

Rotational rigidity tests are required to support the analyses of 4.7.a(2). Free play and wear tests are required to ensure safe free play limits and inspection intervals and to satisfy the requirements of 3.7.1.1a.

VERIFICATION GUIDANCE (4.7.c(3))

If circuit stiffness of control surfaces or tabs is used to prevent any aeroelastic instability, these tests are required.

The rigidity and free play tests for control surfaces, tabs, and flaps should be conducted prior to or during the air vehicle ground vibration modal test of 4.7.d(1). These tests should be conducted for both normal and design failure conditions. Both clockwise and counterclockwise moments should be applied to determine the freeplay and rotational stiffness. Figure 20 shows a load-deflection hysteresis diagram and method for determination of free play and rotational stiffness.

Actuator stiffness tests should be conducted to determine the static stiffness and freeplay of the actuator before and after life cycle testing. In addition, tests should be conducted to determine the dynamic stiffness of the actuator over the range of frequencies for all operating modes, including failure modes, of the system.

VERIFICATION LESSONS LEARNED (4.7.c(3))

Ground vibration tests and ground static stiffness tests on a new, larger all-movable, horizontal stabilizer on a fighter airplane revealed much lower frequencies and rigidity than predicted. More detailed examination indicated the new composite tail was somewhat heavier than the design and had more flexibility in the horn to torque tube attachment than predicted. The horn is loosely fit on the torque tube and is held tight by taper pins. The taper pins were not sufficiently tight and reamed with close enough tolerances to provide sufficient stiffness. Flutter analyses using the reduced stiffness showed much lower flutter speeds than predicted based on design values. To increase flutter speeds, a tighter fit of the horn to torque tube was obtained by shimming the attachment, increasing taper pin preload, and assuring a proper reaming of the holes for taper pins. Periodic stiffness tests on the flight article were planned to check for effects of wear and flight loads with time.

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(4) Component stiffness tests. (___).

VERIFICATION RATIONALE (4.7.c(4))

These tests are required, as necessary, to validate the analyses of 4.7.a. Such components include external store pylons, engine pylons, control surfaces, and other flutter critical components. Component stiffness tests verify that the required stiffness is maintained throughout the envelope of design loads.

VERIFICATION GUIDANCE (4.7.c(4))

Define or list the test required in the blank. Candidate components for test include external store pylon, engine pylons, control surfaces, and other flutter critical components.

Judgment is required in selecting those components requiring a stiffness test. Components with high flutter or divergence margins need not be tested. Components with stability margins less than 1.2 V_L/M_L may be considered as candidates for these tests. Tests should be carried out to 1.2 times limit load. Nonlinearities in deflection with respect to load, as may be caused by buckling, are characteristics to measure. Based upon results, some aeroelastic stability analyses may need to be repeated.

It is often convenient to conduct the stiffness test in parallel with the structural proof tests. Care should be taken that the loading conditions include significant torsion as well as bending.

VERIFICATION LESSONS LEARNED (4.7.c(4))

(5) Balance weight attachment verification tests. (___).

VERIFICATION RATIONALE (4.7.c(5))

These tests are required to demonstrate the integrity of the balance weight installation and satisfy the requirement of 3.7.1.1b

VERIFICATION GUIDANCE (4.7.c(5))

If mass balancing of control surfaces or tabs is used to prevent any aeroelastic instability, these tests are required. These tests include balance weight installation stiffness tests and static and repeated design loads tests.

VERIFICATION LESSONS LEARNED (4.7.c(5))

(6) Damper qualification tests. (___).

VERIFICATION RATIONALE (4.7.c(6))

These tests are required to ensure the integrity of the damper installation and effectiveness in the frequency range of the modes for which damping is required and satisfy the requirement of 3.7.1.1c.

VERIFICATION GUIDANCE (4.7.c(6))

These tests are required if dampers are used to prevent aeroelastic instabilities and if the damper is a part of a new air vehicle design or a new application.

If dampers are used, experimental verification tests should be performed on the damper and supporting structure to ensure that components will not fail under static or repeated loads, that the dampers will not lose their effectiveness under airplane service conditions including operation at high temperatures, and that proper maintenance and inspection under service conditions can be readily accomplished. In addition, free-play measurements should be performed to substantiate that the free play is within the prescribed limits.

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VERIFICATION LESSONS LEARNED (4.7.c(6))

(7) Thermoelastic tests. (_____).

VERIFICATION RATIONALE (4.7.c(7))

Extreme thermal effects as a result of the environment during usage can have a degrading effect on component or air vehicle stiffness characteristics. This, in turn, can adversely affect the aeroelastic characteristics including the flutter characteristics and flutter airspeed margins. Test results from the above tests can be used to validate and update the extent of and the effect of stiffness changes to support the structural dynamic analysis models used in the analyses of 4.7.a.

VERIFICATION GUIDANCE (4.7.c(7))

These tests are required if the analyses of 4.7.a indicate that a critical problem exists as a result of the thermal environment. Full-scale components of the air vehicle should be heated and cooled in a manner to simulate the most critical temperatures to be encountered in flight. The components should 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 should be performed on fully instrumented components or partial components of a test article having restraint or boundary conditions as if installed on the air vehicle. The test article should not have been subjected to yield loads at any time prior to these tests.

VERIFICATION LESSONS LEARNED (4.7.c(7))

d. Air vehicle ground tests. Ground tests shall be performed to obtain data to validate, and revise if required, the dynamic mathematical models which are used in structural dynamic analyses, aeroelastic and aeroservoelastic stability analyses.

(1) Complete air vehicle ground vibration modal tests. (_____) These tests shall be performed on the first Engineering/Manufacturing Development (EMD) aircraft prior to its first flight and on the EMD aircraft to be used for flight flutter tests (if the first EMD aircraft is not used for this testing) prior to its first flight. These tests shall be repeated on the last EMD aircraft (_____).

VERIFICATION RATIONALE (4.7.d(1))

These tests are required to obtain frequencies, mode shapes, and structural damping on the assembled air vehicle to validate the analysis of 4.7.a.

Results from a ground vibration test provide the first opportunity to verify by test the structural dynamic mathematical model of the complete airplane as used in the flutter, aeroservoelastic stability, gust response, and dynamic landing analyses. In some cases the results may be the sole source of information for determining the normal modes of vibration as required for the above cited analyses.

It is the exception rather than the rule that the computed modes agree completely with the test modes. Thus the test results provide a basis for correcting the stiffness and mass distribution data such that analyses only are needed for determining the modes of other or subsequent configurations.

VERIFICATION GUIDANCE (4.7.d(1))

These tests are required if the air vehicle is a new air vehicle or if changes occur which affect the structural dynamic characteristics of an existing air vehicle.

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The objective of the ground vibration test is to measure the structural modes of vibration. The test is accomplished by exciting the structure with a vibratory force and measuring the response. Excitation may be sinusoidal, using several shakers, or random using a single point input, or random using multipoint, uncorrelated inputs. Sinusoidal has the advantage of permitting on-line examination of the modes, easy linearity evaluation of each mode, and minimum reliance upon complex data reduction computing programs. Random testing has the advantage of reducing test time in that the complete set of measurements need not be repeated for each mode and reliance is placed upon the data reduction method in obtaining orthogonal modes rather than on the skill of the vibration test engineer. Random testing may not provide adequate data for all cases, for example nonlinear systems.

In obtaining free-free modes, careful consideration of the vehicle supporting system is required. A support such that rigid body frequencies are less than one-third the frequency of the lowest vehicle structural mode is usually accepted as justifying the use of measured modes as free-free modes. However, if this is not practicable, then the dynamic mathematical model shall be formulated to represent the air vehicle on its test support system for correlation analyses.

Test configurations should include the no-fuel configuration and other fuel configurations deemed to be flutter critical or dynamically significant by analyses. Fuel may be simulated by a suitable liquid.

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

For air vehicles carrying external stores, judgment and analyses should be used to select a sufficient number of store configurations for ground vibration testing to cover the probable range of frequencies that will be encountered.

The air vehicle configurations tested should be equipped with all items having appreciable mass, such as engines and other subsystems, tip tanks, external stores, guns and similar items.

In addition to the test on the complete air vehicle, vibration modal tests should also be performed on components attached to the air vehicle. These components include such items as control surfaces, tabs, flaps, landing gear, landing gear doors, weapon bay doors, turboprop propeller plane, and other auxiliary components attached to the vehicle.

For flutter safety evaluation of skin panels required by 4.7.a(6), the modes and frequencies of skin panels which have been determined to be flutter critical by analyses should be obtained on the aircraft.

The dynamic mathematical model representation of the air vehicle structure should be verified by correlating the modal analyses with ground vibration tests.

VERIFICATION LESSONS LEARNED (4.7.d(1))

In conducting the ground vibration test, care must be taken in orienting the sensitive axis of the pickup. Corrections are required when the sensitive pickup axis is not normal to the reference plane. This correction is especially needed when there is cross axis motion as may occur on the horizontal stabilizer of T-tail arrangement.

As pure planar motion is seldom excited at all points on the structure, quadrature acceleration response should be used for modal definition. Angular motions of lifting surface tips are most important and because of the reduced chord are often the most difficult to measure accurately.

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AIAA Paper No. 78-505 documents a representative case of a complete airplane ground vibration test using transient testing techniques. AFWAL-TR-80-3056 documents a research effort evaluating various ground vibration test techniques.

(2) Aeroservoelastic ground tests of the air vehicle and its flight control augmentation systems. (___) These tests shall be performed on the first EMD aircraft prior to its first flight.

VERIFICATION RATIONALE (4.7.d(2))

These tests determine and validate parameters used in the aeroservoelastic stability analysis of 4.7.a(8). Verification of the stability of the air vehicle/flight control augmentation system (FCAS) is required to ensure that structurally destructive or undamped motions do not occur on the ground and to increase confidence that such destructive or undamped motion will not occur in flight.

Aeroservoelastic ground testing to provide hardware response data for test/analyses correlation is a way of increasing the confidence level in the analytical results and is also a way of identifying or reducing the risks of flutter and aeroservoelastic flight testing.

VERIFICATION GUIDANCE (4.7.d(2))

These tests are required if the air vehicle has a flight control augmentation system.

Aeroservoelastic ground characteristics can be evaluated by conducting open loop transfer function (frequency response) tests and closed loop coupling (structural resonance) tests of the vehicle on the ground. An external signal source can be used for the open loop test. Shakers, as used for the ground vibration test and control inputs, can be used for the closed loop test.

Results in terms of sensor, control surface, and structural response versus frequency should be compared with analysis.

Because of the nonlinear characteristics, flight control augmentation systems should be evaluated at several levels of excitation. A buildup in flight control system loop gains should be evaluated, if possible, in the closed loop tests.

VERIFICATION LESSONS LEARNED (4.7.d(2))

The servoelastic part of the ASE analyses can be substantiated by a wide variety of part ground and flight tests. "Aeroservoelastic Encounters", AIAA Journal of Aircraft, Vol. 16, No. 7, gives a good discussion of the various ground tests.

Three aircraft were ground tested using open loop frequency response test techniques. These ground test results were then used to validate or update the mathematical model used in correlating aeroservoelastic analyses. This aeroservoelastic ground testing and subsequent analysis correlation increased confidence in the aeroservoelastic analysis predictions before flight testing began. AIAA Paper No. 78-505 documents one of these, a transport ground test effort. Another is documented in AFFDL-TR-76-110, a research report basically recommending the above approach and applying it to a prototype fighter (after initial prototype flight testing).

A swing wing bomber encountered a servoelastic instability on the ground during flight control system tests. Though ASE analyses of the vehicle indicated no problem, the aircraft was supported on jacks for these tests and the vehicle's structural dynamics were significantly different from the free flight condition analyzed.

The Control Configured Vehicle Ride Control System (RCS) (see "Interaction Between Aircraft Structure and Command and Stability Augmentation System") tested on a bomber encountered a servoelastic oscillation on the ground that illustrates an inadequacy inherent in

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aeroservoelastic analyses. Local structural vibrations such as those associated with bulkheads or support beams are too detailed to include in the aircraft structural dynamics mathematical model. On the bomber RCS, the excitation of a person walking about in the crew compartment was sufficient to excite the local structure around the accelerometers that provided input to the RCS. By changing the accelerometer mounting, the oscillations were eliminated.

A lateral accelerometer sensor installed on a medium sized transport was moved from a floor location to a center wall location to correct an FCAS 6 Hz rudder instability. The instability was detected during the vibration test portion of the ground stability test and measurements showed the source of the instability was a fuselage shearing type mode in which the floor and ceiling were out of phase and the center wall was modal. The instability was not anticipated because the destabilizing mode, peculiar to the on landing gear condition, had not been accurately defined by analysis. A ground test program on another aircraft with an active control system is documented in "Interaction Between Aircraft Structure and Command and Stability Augmentation System", AGARD Paper, by Sensburg, April 1976.

Prior to the first flight of a demonstrator aircraft, a notch filter was added, frequencies of several notch filters were adjusted, and a gain was changed. These changes were based on the servoelastic ground test results, the ground vibration test results, and the updated aeroservoelastic analysis. The servoelastic ground tests of the aircraft and its flight control system consisted of open loop frequency response tests and closed loop coupling tests. Other aircraft/flight control system ground tests included a limit cycle gain margin test and an impulse (drop) test.

e. Air vehicle flight tests.

(1) Initial flight speed limits. An initial flight envelope shall be established to cover any planned flight testing prior to flight flutter testing. This envelope shall be limited to a maximum speed of _______ percent of V_L/M_L or _______ percent of the predicted flutter speed boundary, whichever is lower.

VERIFICATION RATIONALE (4.7.e(1))

There is typically a need for a safe initial flight test envelope to test a new aircraft (or a modified one) for initial airworthiness, flying qualities, and performance before envelope expansion and flight flutter testing begins.

VERIFICATION GUIDANCE (4.7.e(1))

The above requirement always applies.

The values should be 75 percent and 50 percent for the first and second blanks, respectively.

VERIFICATION LESSONS LEARNED (4.7.e(1))

Experience based on the initial speed envelope typically used at Edwards AFB suggest the 75 percent should be used for the first blank and 50 percent for the second.

Typically, it is desired to test a new aircraft (or a modified one) for initial airworthiness, flying qualities, and performance before they start flutter testing as part of envelope expansion. The average speed margin of safety for the initial speed envelopes since the mid 1970's is over 90 percent (including aircraft which were derivatives of previous tested aircraft). This initial speed envelope is equal to about 50 percent of the predicted flutter boundary which is as suggested in the Guidance section.

(2) Flight flutter tests. (___).

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VERIFICATION RATIONALE (4.7.e(2))

Flight flutter testing of an air vehicle provides final substantiation that the aeroelastic requirements have been met.

VERIFICATION GUIDANCE (4.7.e(2))

These tests are required if the air vehicle is a new air vehicle or if changes occur which significantly affect the flutter characteristics of the air vehicle and particularly if the results of the flutter analyses are doubtful or model tests indicate low speed margins of safety. If these tests are required, this paragraph is applicable.

Flight flutter tests should be performed to substantiate that the airplane is free from aeroelastic instabilities and has satisfactory damping up to limit speeds for the flight conditions defined in Guidance under 4.7.a(1). Flight flutter test results should be used to validate analytical design data, and together with analytical and ground test results should corroborate that the aeroelastic requirements of 3.7 have been satisfied.

Normally, configurations that are deemed most flutter critical from preceding analyses and model tests are flight flutter tested up to the limit speed envelope.

Sufficient instrumentation should be installed and suitable methods of excitation should be used to determine the frequency and amount of damping of the primary modes of interest at each flight test condition. Test configurations should be as follows:

a. Practicable variations in important parameters such as weight, augmentation system gains, etc., should be made covering ranges of these parameters including maneuver conditions.

b. For airplanes with augmentation systems, the tests should be conducted both with the system operating and without the system operating (system off, if a design condition) for speeds at which the unaugmented airplane can be safely flown.

c. If detail design does not provide the recommended free play limits (for control surfaces, tabs, leading and trailing edge flaps, and wingfolds) given in 3.7.4 Guidance, then flutter flight tests should be performed with the established maximum allowable freeplay to substantiate that values of free play that exceed those listed in 3.7.4 Guidance are adequate and satisfy the required margins of safety by extrapolation (if quality of data permits).

d. Airplanes with wingtip mounted stores should be flight tested with and without the store.

e. For airplanes with external stores, the critical airplane store configurations should 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 should be tested in climb, level, and dive attitudes.

Flight tests should 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 should 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, should 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 should be 2,000 feet above ground

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level (AGL) or less, but consistent with safety of flight of the pilot and airplane. Flight tests should 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.

VERIFICATION LESSONS LEARNED (4.7.e(2))

NASA SP-415, AGARD Report 596, and AGARDograph 160 document many representative cases of flight flutter tests and the techniques used.

Some other flight flutter test experiences are briefly discussed in Lessons Learned of 4.7.a(2).

(3) Flight aeroservoelastic stability tests of the air vehicle and its flight control augmentation system. (___).

VERIFICATION RATIONALE (4.7.e(3))

The tests must be done to demonstrate that the aeroservoelastic stability requirements have been met.

VERIFICATION GUIDANCE (4.7.e(3))

These tests are required if the air vehicle has a flight control augmentation system and if the air vehicle is a new air vehicle or if changes occur which significantly affect the aeroservoelastic stability characteristics of an existing air vehicle and particularly if analysis indicates low aeroservoelastic margins of safety. If these tests are required, this paragraph is applicable.

These tests are normally performed in conjunction with the flight flutter tests. See Guidance under 4.7.e(2).

VERIFICATION LESSONS LEARNED (4.7.e(3))

A prototype fighter encountered two different instabilities during early flight tests (see AIAA/ASME/SAE 16th Structures, Structural Dynamics and Materials Conference, Paper 75-823). With the tip missiles installed, the instability occurred at 6.5 Hz and involved coupling of the roll augmentation system with the first antisymmetric, missile pitch mode of vibration. The second instability occurred without the tip missiles. Again the motion was antisymmetric, but involved coupling of the flight augmentation control system with, primarily, rigid body roll motion of the airplane at a frequency of 3.5 Hz. Similarly, another prototype fighter had two potential instabilities (see AIAA/ASME/SAE 16th Structures, Structural Dynamics and Materials Conference, Paper 75-824).

A target drone, when equipped with a prototype infrared wing tip pod, encountered sustained constant-amplitude sinusoidal oscillations at high speeds. On some flights these oscillations produced structural damage to the wing tip area. Because the vehicle's automatic flight control system had no wing control surfaces, aeroservoelastic interaction was not initially considered to be a source of the problem. After further investigations, it was determined that a roll rate gyro in the fuselage was sensing a wing tip pod pitching mode and commanding differential horizontal tail motions. Notch filters and control system gain reductions were used to solve the problem.

Another example of an aeroservoelastic instability that could not be adequately predicted by analyses occurred on a modified fighter, see FTC-TR-73-32. During a sideslip maneuver in a gear-down, flaps-down configuration, a resonance in the pitch axis was encountered. The instability occurred at 23 Hz, which was close to both the flap rotation mode and the stabilator rotation mode frequencies. The instability mechanism was initiated by flap buffet which fed into

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a pitch-rate gyro located in the left wing root just forward of the flap. The resonance was sustained by the pitch-rate-gyro output driving the stabilator. The problem was solved by additional filtering in the pitch axis.

Other flight test programs for aircraft with active control systems are documented in AIAA Paper No. 78-505, NASA Contractor Report 144887, and NASA Contractor Report 159097.

A.3.7.1 Aeroelastic stability.

The airframe in all configurations of the air vehicle shall be free from flutter, divergence, and other related aeroelastic or aeroservoelastic instabilities 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 airframe shall meet the following stability design requirements.

a. Airspeed margin: The equivalent airspeed, V_e, margin of safety at all points on the V_L/M_L envelope of the air vehicle, both at constant Mach number, M, and separately, at constant altitude, shall be not less than ________.

REQUIREMENT RATIONALE (3.7.1.a)

A margin prevents the air vehicle from entering regions of instabilities when accidentally exceeding the envelope and it adds conservatism to the analytically derived flutter boundaries.

Experience has shown that over the life of an air vehicle there is a reasonable finite probability that the limit speed will be exceeded because of gust upsets, control malfunctions or over operational circumstances. Flutter speed margins on V_L/M_L also allow for uncertainties in analyses and for minor operational changes in structural and AFCS system characteristics.

REQUIREMENT GUIDANCE (3.7.1.a)

The above requirement always applies.

For normal conditions, the number in this blank should be not less than 15 percent on V_L/M_L.

If technical justification is not provided and accepted for an alternate criterion for design failure conditions, then the number in this blank should be not less than 15 percent on V_L/M_L. However, technical justification of an alternate criterion such as zero margin on V_L/M_L or a 15 percent margin on V_H/M_H, whichever is greater, may be used.

REQUIREMENT LESSONS LEARNED (3.7.1.a)

Margin criteria for a fighter, where $V_H = V_L$, used a 20 percent margin for normal (i.e., dual hydraulic system) operation and 15 percent for a system failure (i.e., single hydraulic system) operation. A STOL transport airplane used a 15 percent margin for all normal conditions and a zero percent margin on V_L for failure conditions, where V_L was 400 KEAS and V_H was 350 KEAS at the lower altitudes where the airplane was not Mach limited.

In "Some History of Flutter Criteria," Tolve gives the history of the derivation of the flutter speed margin criteria commonly used today (Military 15 percent and FAA 20 percent). Also, a flutter speed margin of 25 percent is used by the United Kingdom (UK) Ministry of Defense.

b. Damping: For any critical flutter mode or for any significant dynamic response mode for all altitudes and flight speeds from minimum cruising speeds up to V_L/M_L, the total (aerodynamic plus structural) damping coefficient, g, shall be not less than ____________.

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REQUIREMENT RATIONALE (3.7.1.b)

Safety considerations require sufficient damping of critical flutter modes or significant dynamic response modes.

REQUIREMENT GUIDANCE (3.7.1.b)

The above requirement always applies.

If 0.03 is not used in the blank for all altitudes and flight speeds up to V_L/M_L, then technical justification shall be provided and accepted for an alternate criterion.

The variation of damping with air speed is as important in assessing aeroelastic stability as is the magnitude of damping. The usual minimum damping requirement of 0.03 g at V_L/M_L indicates that the aerodynamic forces are stabilizing in that the usual zero airspeed damping for all modes is significantly less than 0.03 g. Structural damping less than 0.03 g does not pose a danger for modes involving pods or external stores which are lightly coupled to lifting surfaces and are uninvolved in the critical flutter mode. However, these lightly damped modes may respond easily to turbulence and may have a detrimental effect upon structural fatigue, pilot performance, and store release.

REQUIREMENT LESSONS LEARNED (3.7.1.b)

A slightly modified damping requirement has been used for a primary trainer aircraft program and an air superiority fighter program. The damping requirement for these was that the in-flight damping coefficient, g, at all speeds up to V_L, for any critical flutter mode or for any significant dynamic response mode shall be at least one percent (0.01) above the structural damping measured in the ground vibration test or three percent (0.03), whichever is the smaller value.

A.4.7.1 Aeroelastic stability.

The analyses and tests of 4.7 shall be of sufficient scope to verify that the airframe structure meets the aeroelastic stability requirements of 3.7.1 and subsequent subparagraphs.

a. Airspeed margin. The analyses and tests of 4.7 shall be of sufficient scope to verify that the airframe structure meets the airspeed margin requirements of 3.7.1a.

VERIFICATION RATIONALE (4.7.1.a)

VERIFICATION GUIDANCE (4.7.1.a)

VERIFICATION LESSONS LEARNED (4.7.1.a)

b. Damping. The analyses and tests of 4.7 shall be of sufficient scope to verify that the airframe structure meets the damping requirements of 3.7.1b.

VERIFICATION RATIONALE (4.7.1.b)

VERIFICATION GUIDANCE (4.7.1.b)

VERIFICATION LESSONS LEARNED (4.7.1.b)

A.3.7.1.1 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 or sustained limited amplitude instabilities of all critical modes under all flight conditions for normal and failure operating conditions of the actuating systems.

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a. If circuit stiffness of control surfaces or tabs is utilized to prevent any aeroelastic instability, safe free play limits and maximum allowable inertia properties shall be established which shall not be exceeded during the service life of the airframe. These free play limits shall be as specified in 3.7.4.

b. If mass balancing of control surfaces or tabs is utilized to prevent any aeroelastic instability, mass balance design requirements shall be established. These requirements shall include balance weight installation stiffness, static and repeated design loads for the balance weight installation, and mass balance tolerance for inclusion in maintenance manuals. In addition, the damage tolerance requirements of 3.12 are applicable to the balance weight installation. The static and repeated design loads for the balance weights and the adjacent supporting structure shall be ____________.

c. In the event that mass balance or rigidity criteria are impracticable, two parallel hydraulic dampers may be used to prevent any aeroelastic instability of a control surface, tab, and any other movable component which is exposed to the airstream. In addition, maximum free play limits and minimum and damper capability limits shall be established for the dampers.

REQUIREMENT RATIONALE (3.7.1.1)

The occurrence of flutter within the flight envelope is likely to be catastrophic and measures necessary to improve the flutter characteristics usually cannot be introduced without structural redesign. Control surfaces and tab flutter are the most prevalent type of flutter problems. This type of flutter may occur on all sizes and types of air vehicles. In many cases flutter criteria will strongly influence control surface and tab design with respect to actuator stiffness and mass distribution.

REQUIREMENT GUIDANCE (3.7.1.1)

The above requirements always apply.

Mass balance is required on any control surface (including all-movable surfaces) or tabs that do not have sufficient circuit stiffness to prevent any aeroelastic instability under all flight conditions. If circuit stiffness is used to prevent any aeroelastic instability, adequate stiffness must be provided for both normal and design failure conditions. In determining the adequacy of the stiffness, the rigidity of all actuating elements, the rigidity of the structure to which these elements are attached, and the rigidity of the control surface or tab should be included. In addition, safe free play limits of the control surfaces and tabs should be established, which shall not be exceeded during the service life of the airframe. (see Guidance under 3.7.4)

If balance weights are used on control surfaces or tabs, the following guidelines should be followed:

a. Location of balance weights: Balance weights in control surfaces or tabs should be so located that the flutter safety of both tab and control surface and fixed surface will be assured. The distribution of balance weights should be such that the control surface or tab will be adequately balanced to preclude flutter. Preferably, balance weights should not be located externally with respect to the planes of the control surfaces. On airplanes which experience high-acceleration takeoffs, such as by catapulting or rocket assist, the mass balance weights and actuation systems for control surfaces and tabs should be designed to prevent control surface rotations resulting from inertia loads acting on the balance weights and actuating systems.

b. Rigidity and strength of balance weight attachment:

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(1) The natural frequencies of vibration of the balance weights as installed should be at least twice the highest frequency of the flutter mode for which the balance weight is required to be effective.

(2) If the values (from MIL-A-8870C(AS)) for the static and repeated design loads for balance weights and the supporting structure given below are not used for the blank, then technical justification shall be provided and accepted for more rational higher or lower values.

A limit inertia load factor of +/-100g and repeated inertial loads of +/-60g for 500 kilocycles in a direction normal to the plane of the control surface tab. In addition, a limit inertia load factor of +/-50g and repeated inertial loads of and +/-30g for 500 kilocycles in the other two mutually perpendicular directions of the control surface or tab.

c. Provisions for rebalancing: Provisions should be made to enable increasing or decreasing the mass-balance weights to compensate for effects of changes, repairs, and painting.

d. Static balance tolerance: The maximum allowable service static unbalance of each surface including tabs and the manufacturing tolerances should be included in all control surface and tab assembly drawings and in appropriate user manuals.

In the event that mass balance or sufficient circuit stiffness is impracticable, two parallel hydraulic dampers may be used for the prevention of flutter. Flutter analyses or flutter model tests should be performed to ensure that the obtainable damping from a single damper is sufficient to prevent flutter. The rigidities of the damper elements and the supporting structure to which the elements are attached should be sufficiently high to preclude loss of damper effectiveness by structural deformation at the flutter frequencies. The free play of the damper should not exceed that established as safe limits for control surfaces or tabs.

REQUIREMENT LESSONS LEARNED (3.7.1.1)

Excessive free play of circuit stiffness designed control surfaces often results in a limited amplitude oscillation which, if uncorrected, may cause a fatigue failure leading to large amplitude flutter and destruction of primary structure. Proper maintenance is essential and many tab flutter incidences have occurred because of failure to service the actuator properly or failure to connect the actuator to the tab. Dual actuation or one actuator together with mass balance provides safety from this type of failure.

Accurate modes of vibration as used in the flutter analysis are important in determining proper mass balancing of control surfaces. Control surface flutter has occurred because of insufficient mass balance at the surface tip even though the original design was uniformly balanced. Control surface flutter has also occurred as a result of loss of balance weights.

Hydraulic dampers present difficulties in establishing maintenance methods or in designing indicators which may be required to ensure operational reliability. This lack of ensurance, together with the large amount of damping usually required, often discourages the use of hydraulic dampers as a means of preventing control surface coupled flutter.

In MIL-A-8866(ASG), the following static and repeated design loads for the balance weights and the adjacent supporting structure were specified:

> "A limit load factor of +/-100g and a repeated inertial factor of +/-60g for 500 kilocycles in a direction normal to the plane of the surface or tab. In addition, a limit inertial load factor of +/-30g in the other two mutually perpendicular directions of the control surface or tab."

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Mr. Tolve in "Some History of Flutter Criteria" states that these load factor design requirements were probably due to an incident encountered by a F-86 airplane during high speed flight. The elevators had oscillated due to compressibility buzz and the balance weights had failed. It was determined that it would have required a very high g loading (approximately 100g) to have failed the balance weights.

In 1971 the Industry Working Group considered that these static and repeated design loads for the balance weight and the adjacent structure were overly conservative for large aircraft that are designed to low load factors. They recommended that the required balance weight load factors should be a function of the airplane design load factor.

Using this rationale in part, static and repeated design loads for the balance weight and the adjacent supporting structure used for a large cargo aircraft were:

(1) a limit load factor of +/-N_2 and repeated inertial loads of +/-N_1 for 500 kilocycles in a direction normal to the control surface or tab. In addition, a limit load factor of +/-N_3 in the other two mutually perpendicular directions of the control surface or tab.

(2) where, N_1 was defined as the maximum normal direction load factor (as determined from measured data and predicted gust response), and N_2 and N_3 were defined as 1.5 times the normal and in-plane factors, respectively. In absence of balance weight load factor data, the values 60, 100, and 30 were substituted for N_1, N_2, and N_3, respectively.

For this particular large cargo, the maximum inertial load factors N_1 were determined to be +/-17g for the aileron balance weight and +/-25g for the outboard elevator balance weight. N_2 was then +/-25.5g and +/-37.5g for the aileron and outboard elevator balance weights, respectively. N_3 was undefined and +/-30g was used.

Another large cargo aircraft used the following for the static and repeated design loads for the balance weights and the adjacent supporting structure:

Aileron: An ultimate load factor of +/-60g and repeated inertial loads of +/-30g for 500,000 cycles in a direction normal to the control surface. In addition, repeated inertial loads of +/-15g for 500,000 cycles in the other two mutually perpendicular directions of the control surface.

Outboard and inboard elevator: An ultimate load factor of +/-60g and repeated inertial loads of +/-40g for 500,000 cycles in a direction normal to the control surface. In addition, repeated inertial loads of +/-20g for 500,000 cycles in the other two mutually perpendicular directions of the control surface.

The +/-30g and +/-40g repeated inertial load requirements were greater than that measured in flight testing, and the +/-40g repeated inertial load requirement was consistent with what was used on a similar commercial transport aircraft.

All balance weights and adjacent supporting structure of a medium cargo airplane were designed to limit loads of at least 57g normal to the plane of the structure and at least 36g in the other two mutually perpendicular planes.

On the other hand, the old MIL-A-8866(ASG) or the Guidance recommended design values above for balance weight attachment strength and repeated loads, have been unconservative for certain fighter aircraft. An air superiority fighter during flight at high load factor and high angle of attack, experiences high levels of vibration at the tips of the twin vertical tails where pods are located containing flutter ballast weight and various electronic equipment. Early in the aircraft operational life, the tip pod acceleration levels were measured in flight to be as high as

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250g's. The vibration caused cracking of secondary structure and damaged equipment. Also the forward part of the pod with the flutter ballast weight was broken completely off during flight in one case and cracked in several other cases. This flutter ballast weight problem resulted in a temporary speed placard to avoid encountering flutter at high speed if the flutter ballast weight were to be broken off by vibrations during earlier maneuvers. Equipment changes, secondary structural changes and stiffer forward pod with better ballast weight attachment were accomplished to better withstand the environment. Also after a reduction in the required flutter ballast weight was substantiated, the resulting dynamic response was reduced and the measured levels are now in the 180g range. Wind tunnel tests showed the source of the vertical tail excitation to be flow from the wing leading edge which moves upward and inward to impinge on the upper part of the vertical tails when the aircraft is at a certain high angle of attack region.

During an investigation of the cause of a permanent set deformation in the elevator of a small attack aircraft, in-flight measurements showed dynamic response acceleration levels on the elevator balance weight to be as high as 60g 's during excursions into the aircraft stall buffet regime. The flight investigation revealed a severe load condition on the outboard section of the elevator during transition into aircraft stall buffet and structural modification were made to the elevator and hinges to ensure its structural integrity.

"Historical Development of Aircraft Flutter" and NACA RM-56112 document many past airframe flutter incidents. For example, 33 flutter incidents are listed for US military aircraft in the ten year period of 1947-1956 and 16 of these involved control surface and tab flutter.

A.3.7.1.2 Divergence.

Aerodynamic surfaces and components of the air vehicle shall not aeroelastically diverge.

REQUIREMENT RATIONALE (3.7.1.2)

Divergence is a static aeroelastic instability of a lifting surface or component that occurs when the structural restoring moment of the surface is exceeded by the aerodynamic torsional moment. Divergence of a lifting surface would likely result in loss of the air vehicle. Divergence of a component would likely result in loss of that component.

REQUIREMENT GUIDANCE (3.7.1.2)

This requirement always applies.

REQUIREMENT LESSONS LEARNED (3.7.1.2)

Aft sweep of lifting surfaces prevents divergence. Divergence usually limits the speed of air vehicles with forward swept surface unless the structure is exceedingly rigid or directionally tailored to increase the divergence speed. This tailoring may be accomplished through the use of filamentary composite materials such as graphite epoxy. On primary forward swept lifting surfaces such as wings, the reduction of the fundamental mode frequency due to aeroelastic characteristics of a divergence prone surface (either the primary surface or an ancillary surface such as leading edge flap) may result in coupling with the airplane rigid body short period mode. In this case, a flutter-type instability may occur at a speed less than the fixed surface divergence speed (see "Flutter of Forward Swept Wings, Analyses and Tests").

Another divergence possibility is that associated with landing gear doors in the extended positions; also gapping under load factor may result in divergence when the doors are closed. Access doors improperly fastened have also been lost.

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"On the Track of Practical Forward-Swept Wings"; NASI-15080-Task #16; AIAA Paper No. 82-0683; "Flutter of Forward Swept Wings, Analyses and Tests"; NACA TN 1680; "Divergence of Forward Swept Composite Wings"; AIAA Paper No. 80-0796; AFWAL-TR-80-3059; and AFWAL-TR-80-3073 document primarily research and development efforts in forward swept wing aircraft technology.

A.3.7.1.3 Buzz. (___)

Control surfaces and parts thereof shall not buzz.

REQUIREMENT RATIONALE (3.7.1.3)

Buzz of control surfaces can lead to damage or destruction of the surfaces by fatigue or by inducing greater than yield loads when the amplitudes are sufficiently large.

REQUIREMENT GUIDANCE (3.7.1.3)

If transonic flow can possibly exist over control surfaces, this paragraph is applicable.

REQUIREMENT LESSONS LEARNED (3.7.1.3)

Control surface buzz was experienced on the first transonic aircraft and was one of the most common type of aeroelastic instabilities in the late 40's through the mid 50's; however, most recent aircraft have sufficient actuator stiffness or circuit stiffness to avoid encountering control surface buzz. Also, experience has shown that not all control surfaces buzz when exposed to transonic or supersonic flow.

However, there are three USN airplanes currently in service that have experienced rudder buzz even with a powered control actuator. The mechanism was caused by oscillating shocks on the fixed fin forward of the rudder. These three aircraft had the rudder buzz stopped by installing tripper strips (about 1/2 inch high) on the fins' mid span and running vertical for most of the fins' spans.

Reliable buzz predictions do not exist at this time; however, empirical criteria for avoidance of buzz can be used such as that in "Flutter of Control Surfaces and Tabs." The possibility of buzz is reduced with increasing hinge line sweep and decreasing thickness ratio. Buzz is prevented by sufficient circuit stiffness (e.g., high performance aircraft using powered actuators), low hinge-line moment of inertia, or dampers or proper local flow control. However, buzz may occur when powered actuators are located near the end of control surfaces having insufficient torsional rigidity.

AIAA-81-0591-CP and NACA RM-56112 document many past control surface buzz incidents. For example, 21 incidents of transonic control surface buzz are listed for US military aircraft in the ten year period of 1947-1956. NLR TR 77090U includes a wind tunnel examination of the physics of transonic control surface buzz. Also, a good brief discussion of control surface buzz is given by Cunningham in the reference "Practical Problems: Airplanes".

A.3.7.1.4 External store carriage. (___)

The airframe shall be designed to prevent flutter, divergence, sustained limited amplitude instabilities, and other related aeroelastic or aeroservoelastic instabilities when combinations of prescribed stores are carried on the air vehicle. The stability design requirements of 3.7.1a, 3.7.1b, and 3.7.2 shall apply on the limit speed (V_L/M_L) envelope specified for the air vehicle with stores.

REQUIREMENT RATIONALE (3.7.1.4)

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The carriage of external stores, especially on wing pylons, can adversely affect the flutter characteristics of an aircraft. The inertial, elastic, and aerodynamic coupling between the primary structure and its stores is critical in modifying the flutter speed of the vehicle.

REQUIREMENT GUIDANCE (3.7.1.4)

If the air vehicle carries external stores, this paragraph is applicable.

As a first step in the aeroelastic analyses, characteristics of each store should be identified as follows:

(1) Mission and flight conditions.

(2) Primary structure to which store is attached: lifting surface (wing) or non-lifting surface (fuselage).

(3) Store attachment structure (pylon/rack) flexibility and inertial properties.

(4) Store mass properties (mass, c.g. location, and mass moments of inertia) with respect to a store attachment reference point on the aircraft.

(5) Store classification as rigid, flexible, or moving mass (slosh).

(6) Store aerodynamics.

(7) Damping or nonlinear (free-play, etc.) mechanisms in the store/pylon/rack structure.

The significance of each of these characteristics for a specific airplane must be determined to develop an overall flutter clearance program. Clearly all possible store loadings attainable in flight must be addressed--not only take-off configurations and derivable loadings resulting from normal store release, but also release failure or hung store conditions--but this does not mean that a specific flutter analysis for each attainable loading must be performed. Indeed, for some attack aircraft, the number of possible store loadings becomes so large (thousands, hundred thousands, or more) that separate flutter analyses are not feasible. In this case, the engineering judgment and experience of the analyst is invaluable in grouping store loadings on the basis of the previously identified characteristics to permit a manageable number of specific flutter and divergence analyses along with tests as discussed in 4.7 to produce an aeroelastic clearance for all of the store loadings to the aircraft velocity limits.

REQUIREMENT LESSONS LEARNED (3.7.1.4)

A primary objective of the program to establish flight compatibility for external stores for an attack aircraft was to assure flutter-free performance throughout its flight regime for a wide range of mission-required armament configurations. The design approach required the basic bare wing to have a flutter speed well above the defined flight boundary. In this manner, a margin of safety was allowed for the reduction in aircraft flutter speed due to store carriage. In only a few cases was this margin inadequate to preclude flutter within 1.15 times the aircraft limit speed with a particular store configuration. This approach, however, for some aircraft designs could result in performance penalties for the clean aircraft and still have inadequate flutter clearance speeds for store configurations added later. In order to perform an adequate investigation of the large number of external store/suspension rack/pylon combinations which were dictated by the mission requirements, it was necessary to develop a comprehensive wing/store flutter clearance procedure. The development of this procedure, which utilized results from analytical studies, flutter model tests and flight flutter tests, was based on the establishment of a relation between store inertial properties and wing/store flutter characteristics. This procedure, in essence, predicts aircraft flutter speed on the basis of the

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inertial properties of the wing/pylon loads and was found very effective in handling the large number of store configurations which had to be investigated.

A parametric approach was used to certify variant versions of a missile for carriage on the wing tip of a fighter in combination with all authorized pylon store loadings. The success of the parametric approach in this application was greatly aided by the availability of an extensive body of data generated in earlier stores certification programs, which permitted identification of the flutter sensitive pylon store loadings. Consequently, the parametric program could then concentrate primarily on the tip missile variations. The pylon store configurations analyzed were based on results of previous stores certification programs and the objective to analyze enough configurations to adequately represent all possible store loadings authorized for the aircraft. Extensive parametric flutter analyses were then conducted using a perturbation technique, to cover the range of missile variants for each pylon store loading analysis set. Inert missiles, ballasted to obtain the required properties, were used in flight flutter tests of the more critical missile variant/pylon store loading configurations. Spot checks of less sensitive configurations were also made to ensure that a representative sample of the complete stores matrix was examined. The combined analysis and test program showed that wing tip missile mass property variations within the defined limits, introduced no flutter trends which differed significantly from those established in earlier programs. No new flutter sensitive pylon store loadings were identified.

Under full scale development (FSD), a fighter/stores flutter program consisted of an integrated program of: extensive flutter analyses, pylon component stiffness and vibration tests, airplane ground vibration tests of representative and flutter sensitive or critical configurations, transonic complete airplane flutter model tests to further determine characteristics of flutter critical configurations, and flight flutter tests of the more critical configurations. A parametric approach of flutter analyses and flight flutter tests, similar--but of lesser extent--to that of the fighter discussed in the paragraph above, was used to certify the missile variants for carriage on the wing tip of this fighter. The flutter certification of configurations on the FSD list is completed with all initial take off loadings and downloadings cleared to the desired limits. In the follow-on stores clearance program, the approach followed in FSD is essentially being extended, but with most emphasis on flutter analyses and flight flutter tests, while using the knowledge gained in all previous stores flutter clearance work to help scope the effort and help identify the flutter critical or flutter sensitive configurations. Many store configurations in this follow-on stores clearance program exhibited and were limited to Limit Cycle Oscillations (LCO), as noted in the paragraph below:

Several fighter aircraft with certain wing external store configurations have experienced Limit Cycle Oscillations (LCOs) in flight. This LCO has primarily occurred in the transonic speed regime and is a transonic non-linear flutter. LCO is a limited amplitude self-sustaining oscillation produced by a structural/aerodynamic interaction. The phenomenon is related to buffet but has characteristics similar to classical flutter in that it usually occurs at a single frequency. From an operational point of view, LCO results in an undesirable airframe vibration that limits the pilot's functional abilities and produces extreme discomfort and anxiety. More importantly, targeting accuracy is degraded, e.g. wing mounted missiles cannot be fired because of high levels of wing motion that prevent target lock-on.

An analysis of steady wind tunnel data, obtained for a fighter type aircraft, has indicated that shock-induced and trailing-edge separation plays a dominant role in the development of LCO at transonic speeds. On this basis, a semi-empirical LCO prediction method has been developed which makes use of such steady wind tunnel data. The preliminary method has been applied to several configurations and has correctly identified those which have encountered LCO. The method has the potential for application early in the design process of new aircraft to determine

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and understand these non-linear aeroelastic characteristics. A paper by J.J. Meijer and A.M. Cunningham, Jr. in AGARD-CP-507 describes this LCO semi-empirical prediction method development.

Active flutter suppression systems were the subject of extensive investigations in the 1970's and 1980's culminating in flutter model wind tunnel tests and limited flight tests (AGARD Report No. 668, AIAA Paper 80-0768, AFFDL-TR-72-116, AFFDL-TR-74-67, AFFDL-TR-78-65, AFFDL-TR-78-113, AFWAL-TR-80-3093, AFWAL-TR-82-3040, AFWAL-TR-82-3044, and AFWAL-TR-83-3046). Modern fighter/attack aircraft with wingtip mounted missiles are prone to experience an aeroelastic instability referred to as Limit Cycle Oscillation (LCO). To reduce the vibratory response at the pilot seat, one aircraft has incorporated a rudimentary active flutter suppression system through the aircraft basic flight control system using production sensors installed in the aircraft. This system, known as the Active Oscillation Controller (AOC) is intended primarily to minimize the effects of the LCO on the aircrew without impacting the airframe or system structural service life (fatigue). Depending on its effectiveness for a particular loading, it also minimizes or eliminates the flight placard restrictions that would otherwise be necessary.

Another concept, for possible use, is passive control of wing/store flutter by use of a decoupler pylon system which has been demonstrated through flutter analyses and wind tunnel flutter model tests (AFFDL-TR-74-67 and AFFDL-TR-78-65). A flight demonstration program was accomplished by NASA to evaluate the concept under operational flight environment.

A.3.7.1.5 Panel flutter. (___)

External, inlet, transparency, and other aerodynamically loaded panels shall be designed to prevent flutter and sustained limited amplitude instabilities, and satisfy the stability design requirements of 3.7.1a and 3.7.1b.

REQUIREMENT RATIONALE (A.3.7.1.5)

Although panel flutter is not often catastrophic, the serious effects that have been encountered include very high noise levels within the occupied compartments and panel failure due to fatigue or failure of attached components or structure which can result in flight safety problems.

REQUIREMENT GUIDANCE (A.3.7.1.5)

If supersonic flow exists over any part of the air vehicle, this paragraph is applicable.

REQUIREMENT LESSONS LEARNED (A.3.7.1.5)

Accurate prediction of panel flutter is uncertain because this phenomena is highly dependent upon the static-in-plane and out-of-plane forces. Further, the occurrence of panel flutter is rare and seldom results in a dangerous condition. Nevertheless, identification of regions of supersonic flow is important to alert the design team of the possibility and thereby avoid a costly redesign and rework program. An example is that of a low aspect ratio panel on a commercial transport which was originally designed on the basis of acoustic fatigue. After failures, following several months of operational use, the flutter group realized that the panel was exposed to supersonic flow and the panel was successfully redesigned to prevent panel flutter.

During initial deployment of an air supremacy fighter aircraft, several large, thin, flat panels on the outside of the engine inlet encountered cracking problems caused by panel flutter. These panels were redesigned (stiffened) to prevent panel flutter.

This same aircraft during developmental testing encountered cracks and subsequent fuel leaks in an area of the upper forward, inboard wing skin. After investigation this problem also was

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attributed to panel flutter and the redesign involved stiffening the wing skin in this area to prevent further problems.

Panel flutter prevention criteria were used to a large extent for panels on a swing wing bomber.

A.3.7.1.6 Transonic aeroelastic phenomena. (___)

Lifting surface or other air vehicle components shall be designed to meet the stability design requirements of 3.7.1a and 3.7.1b when exposed to shock induced separation oscillations or other related aeroelastic instability phenomena peculiar to the transonic flight regime.

REQUIREMENT RATIONALE (A.3.7.1.6)

Shock induced separation can induce destructive structural instabilities or limit cycle motions leading to fatigue failures. Also for wings with supercritical airfoil shapes, the available flutter data indicates that flutter can be much more critical in the transonic speed range than for wings with conventional profile.

REQUIREMENT GUIDANCE (A.3.7.1.6)

If transonic flow exists over any portion of the airframe, this paragraph is applicable.

Lifting surface shock induced separation oscillations or other related transonic aeroelastic instability phenomena should be investigated by model tests and during flight flutter tests in the transonic speed range. The model tests should be conducted on as large a scale model as practical and both model and flight flutter tests should investigate damping trends for angles of attack as high as practicable. As satisfactory semi-empirical or CFD analytical methods become available, the design should be evaluated theoretically.

The distinction between flutter at transonic speeds and either purely subsonic or supersonic speeds is the coupling of unsteady aerodynamic forces with the steady mean flow. The presence of shocks and flow separation influences the unsteady forces and hence flutter characteristics. As a result, aircraft attitude, control surface deflection, aeroelastic effects, Reynolds number, and boundary layer transition are all identified as having potential for affecting flutter at transonic speeds. Even though models are recommended, caution is expressed in the use of flutter models to identify these nonlinear effects as a result of not being able to accurately simulate the mean flowfields.

Although control surface buzz is a transonic phenomenon and is a direct result of shock induced trailing edge separation, it has been common enough to be treated in a separate requirement on buzz, 3.7.1.3.

REQUIREMENT LESSONS LEARNED (A.3.7.1.6)

Usually aeroelastic instabilities are critical in the transonic regime. The amplitude of transonic flutter may be limited or may diverge and apparently is strongly influenced by shock induced separation coupling with structural oscillations. Other related transonic phenomena have also been encountered as discussed below.

Edwards and Malone in a current status paper in AGARD-CP-507 describe the main features of transonic flow. Figure 21 shows a diagram of attached, mixed, and separated flow regions for a complete aircraft at freestream Mach numbers between 0 and 2.0. For a given air vehicle configuration, at subsonic speeds and/or low angles of attack, the flow is attached (Region I of figure 21). After entering the transonic region, as speed and/or angle of attack increase, a transition region of mixed flow encountered (formation of shock waves and the onset of flow separation: Region II of figure 21). For rigid structures, this region is typified by the onset of localized regions of flow separation which may exhibit significant aerodynamic unsteadiness.

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For realistic flexible structures, the aeroelastic response of the structure interacts with the airflow to induce much more complicated situations. For instance, structural vibrations can cause the flow to alternately separate and reattach at flow conditions where a rigid structure would support the attached flow. The associated high unsteady aerodynamic loading can interact with the structure to cause unusual aeroelastic phenomena which may restrict the vehicle flight envelope.

With further speed and/or angle of attack increases which may be encountered under maneuvering conditions, fully separated flow conditions emerge (Region III of figure 21). Leading edge vortex bursting in the vicinity of the aircraft can cause severe buffeting (see 3.2.14.3(f) for buffeting requirements and further discussion). Within such regions, the flow is highly unsteady and accurate computations will require careful attention to turbulence modeling. To emphasize the complexity which the aeroelastic response adds, the flow within the three regions of figure 21 will be referred to as Type I, II, and III, respectively.

Edwards and Malone further point out that while the predictive methods for attached flows are reasonably well developed, the picket fence in figure 21 emphasizes the difficulty in predicting aeroelastic Phenomena in the mixed and separated flow regions. It also symbolizes novel features that are being encountered in transonic flutter testing. Modern high performance aircraft (particularly fighter type) are capable of maneuvering at transonic speeds, leading to a much enlarged parameter space that must be considered in flutter analysis and testing. Wing/store loading, fuselage interference, angle-of-attack, Reynolds number, wing shape, and wing sweep all must be considered, and the traditional flutter boundary parameterization of dynamic pressure at flutter versus Mach number may need to be augmented to adequately describe aeroelastic stability boundaries.

Edwards and Malone further discuss features of high speed, low angle flutter. Usually, dynamic pressure at flutter tends to decrease with increasing Mach number to a minimum “critical flutter point” value in the transonic speed range. At subsonic speeds where the flow can be assumed to be attached (Type I flow) at flutter, linear theory is reasonably accurate. As speed increases to the transonic region, the situation is complicated by the formation of shock waves and the onset of flow separation (Type II flow) and linear theory must be used with caution. In this region there is a potential to encounter nonclassical aeroelastic response and instabilities. Figures 22 through 24 illustrate several types of novel aeroelastic responses that have been encountered with the onset of Type II flows.

Figure 22 (from Edwards and Malone) shows a region of nonclassical aeroelastic response observed on a wind tunnel model of a high aspect ratio, supercritical wing where high dynamic response at nearly constant Mach number was encountered at dynamic pressures well below those for which flutter was predicted with linear theory (see reference “Measured Unsteady Transonic Aerodynamic Characteristics of an elastic Supercritical Wing”). The motion was of the limited amplitude type and the response is believed to be associated with flow separation and reattachment driving the wing motion in the first bending mode. A second phenomenon, illustrated on figure 23, is the wing/store limited amplitude oscillations experienced by several high performance fighter aircraft under various loading and maneuvering conditions at transonic Mach numbers (see Limit Cycle Oscillation case in Lessons Learned of 3.7.1.4). Such oscillations can result in limitations on vehicle performance. The conditions for which this type of response occurs appear to also be near the onset of Type II mixed flow. The response typically increases for maneuvering conditions. The occurrence of limit cycle oscillations (LCO’s) of lifting surfaces can be described as a nonlinear coupling between structural response and unsteady aerodynamic forces as well as being strongly dependent on the steady mean flowfields. These oscillations usually appear as sinusoidal motions of a single vibration mode at conditions that may be close to expected flutter. Thus, the differentiation between

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LCO and incipient flutter is difficult to determine because of safety restrictions with either flutter models of flight test.

A third phenomenon consists of dynamic vortex-structural interactions causing wing oscillations that were experienced, figure 24 (from AIAA Paper 85-0739), on a swing wing bomber aircraft for high wing sweep conditions during wind-up turn maneuvers. The flow involved the interaction of the wing vortex system with the wing first bending mode and occurs over a wide Mach number range at moderate angles of attack.

Although caution must be used because of not being able to accurately simulate the mean flowfields, model tests have been used to investigate various types of transonic phenomena. Of the three types discussed above, only the second type -- that involving wing/store LCO -- has not been demonstrated to at least some degree in a wind tunnel model test investigative program. However, even in this case a semi-empirical LCO prediction method (see paper by Meijer and Cunningham in AGARD-CP-507) uses steady wind tunnel pressure model data for a given configuration and also, unsteady force and pressure model data were necessary to properly quantify the aerodynamic driving and damping forces that were important for developing a consistent LCO model.

Although computational fluid dynamics methods for aeroelastic applications are not yet routinely used, Edwards, in a technical evaluation report of conference papers in AGARD-CP-507, concludes that:

(1) Inviscid computational aeroelastic analysis has matured to the point where rather complete configuration details are being treated for cases of transonic flutter and aileron reversal, yielding improved predictions over linear theory.

(2) Inclusion of unsteady viscous effects at the Navier-Stokes equation level is available, but is too expensive for routine aeroelastic analysis or design. Viscous-inviscid interactive boundary layer capability shows promise, but has not yet matured for lifting surface applications.

(3) Experimental and computational efforts are focusing upon flow conditions which define the boundary of current analysis capability: situations in which the flow is near separation, or alternately separating and reattaching.

Cunningham in the reference “Practical Problems: Airplanes” gives a good discussion of all the known important effects of unsteady transonic phenomena as they affect aircraft.

A.3.7.1.7 Whirl flutter. (___)

For air vehicles equipped with propeller, or proprotor engines, the propeller, powerplant, mounting systems, and pylons in combination with other components of the air vehicle shall be designed to prevent whirl flutter.

REQUIREMENT RATIONALE (A.3.7.1.7)

Whirl flutter can occur in a flexibly mounted prop engine or large, turbofan engine. If this problem occurs, the result is usually loss of the engine and has resulted in the loss of the aircraft.

REQUIREMENT GUIDANCE (A.3.7.1.7)

If the air vehicle is propeller driven or is powered by large turbofan engines, this paragraph is applicable.

REQUIREMENT LESSONS LEARNED (A.3.7.1.7)

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Occurrences of whirl flutter have been rare; nevertheless, it is an important design consideration as was emphasized by an incident which led to the destruction of two turboprop aircraft. Correct stiffness with sufficient strength design installations are usually stable. As was the case of the incident cited, the problem develops following a structural failure; therefore, to insure stability, it is important that sufficient structural rigidity is retained following the failure of any member of the structure that supports the propeller gearbox assembly. Studies and tests have shown whirl flutter to be sensitive to damping. Experimentally there are usually difficulties in exciting the mode. Turbofans that are analyzed using aerodynamic terms as developed for an uncowled propeller will result in conservative solutions in that the inlet duct reduces the free-stream inflow angles.

A.3.7.1.8 Other controls and surfaces. (___)

Air vehicle components which are exposed to the airstream shall be designed to prevent any aeroelastic instability. These components shall include, but are not limited to, leading edge flaps, trailing edge flaps, spoilers, dive brakes, scoops, landing gear doors, weapon bay doors, ventral fins, movable inlet ramps, movable fairings, and blade antennas.

REQUIREMENT RATIONALE (A.3.7.1.8)

The serious effects that can happen include component failure due to fatigue or failure of attached components or structure which can result in flight safety problems.

REQUIREMENT GUIDANCE (A.3.7.1.8)

When not displaced from the retracted position in flight, flaps extending outboard of the 50-percent-span station of the main surface should, if practicable, be rigidly locked in the retracted position. Airplane components which may be exposed to the airstream and which can be important with respect to flutter (including, but not limited to, trailing-edge flaps which are impracticable to lock, dive brakes, spoilers, weapon bay doors, movable inlet ramps, movable fairings, scoops, leading-edge flaps, and fixed, retractable, or jettisonable ventral fins) should be made free from flutter by suitable mass balance, hydraulic dampers, structural rigidity, or circuit stiffness of control systems. The circuit stiffness criteria for control surfaces specified in 3.7.1.1a should be applied. In cases where mass-balanced reversible spoilers are employed, coincidence between the spoiler rotational natural frequency and low natural frequencies of the main supporting structure should be avoided in order to prevent objectionable, lowly damped, gust excited oscillations.

REQUIREMENT LESSONS LEARNED (A.3.7.1.8)

Weapon bay doors, movable inlet ramps and movable fairings have been included in the list of components of other controls and surfaces based on the analytical and model test investigations which were conducted for two bombers.

A.3.7.2 Aeroservoelasticity.

Interactions of air vehicle systems, such as the control systems coupling with the airframe, shall be controlled to prevent the occurrence of any aeroservoelastic instability. The operative states (on and off) of the systems shall be commensurate with the uses authorized in the flight manual as applicable throughout the full flight envelope. The air vehicle structural modes shall have the following stability margins for any single flight control system feedback loop at speeds up to V_L/M_L.

a. A gain margin of at least __________.

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b. And separately, a phase margin of at least _______________.

REQUIREMENT RATIONALE (A.3.7.2)

Although aeroservoelasticity instabilities when encountered are generally limited in amplitude by the capacity of the control system, they can be potentially destructive instabilities if the airframe structural strength limits are exceeded. The flight control augmentation system (FCAS) can also degrade or enhance the basic unaugmented (FCAS off) aircraft flutter speed boundaries.

REQUIREMENT GUIDANCE (A.3.7.2)

If the air vehicle has an active flight control system, fill the blanks with the appropriate numbers.

If at least 6dB gain margin and, separately, at least 60 degree phase margin are not used for the blanks, then technical justification shall be provided and accepted for alternate criteria.

The same flutter margins and damping requirements are to be met with the augmentation system on and off (if off is a design condition).

REQUIREMENT LESSONS LEARNED (A.3.7.2)

The possibility of aeroservoelastic instabilities increases as the responsiveness of control systems increases to meet the new demands of flight control, autolandings, reduced static stability, maneuver load control, gust load alleviation, and flutter suppression. Avoidance of costly redesign efforts requires close coordination between the control designers and the aeroelastician. Sensor location and system transfer function characteristics are essential design considerations as are the unsteady aerodynamic characteristics of the control surfaces. Ground operation is a design consideration as are all areas of the flight spectrum.

"Interaction Between Aircraft Structure and Command and Stability Augmentation System" used a 6 dB margin on the amplitude of every structural mode and applied the above philosophy only for failure cases. These strict requirements are necessary if there are several uncertainties (e.g., nonlinearities) in the analysis.

If current state of the art analysis and test techniques are used and if the analysis is updated based on test data as outlined in the recommendations of "Aeroservoelastic Encounters," a 6dB gain margin and a 45 degree phase margin appears to be satisfactory. The flight control system specification provides gain and phase margins in terms of various frequency and speed ranges and can be used as guidance.

Also see Lessons Learned under A.4.7.a(8), A.4.7.d(2) and A.4.7.e(3).

A.4.7.2 Aeroservoelasticity.

The analyses and tests of 4.7 shall be of sufficient scope to verify that the airframe structure meets the aeroservoelastic stability requirements of 3.7.2.

VERIFICATION RATIONALE (A.4.7.2)

None required.

VERIFICATION GUIDANCE (A.4.7.2)

None required.

VERIFICATION LESSONS LEARNED (A.4.7.2)

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A.3.7.3 Fail-safe stability.

After each of the failures listed below, the air vehicle shall be free from flutter, divergence, and other related aeroelastic or aeroservoelastic instabilities. The stability design requirements of 3.7.1a, 3.7.1b, and 3.7.2 shall be met after each of these failure conditions. In addition, this fail-safe criteria shall include air vehicle augmentation system failures and any other failures that occur at a rate equal to or more frequent than the rate specified in 3.1.2 for loss of adequate structural rigidity or structural failure leading to the loss of the air vehicle.

a. Failure, malfunction, or disconnection (except those specifically identified in 3.7.3.c.(1) and 3.7.3.c.(2)) of any single element or component 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 3.7.1a, 3.7.1b, and 3.7.2 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 air vehicle. In addition, the damage tolerance requirements of 3.12 shall apply.

(1) Failure of any single element in any hinge mechanism and its supporting structure of 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 air vehicles 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 or pitch rigidity of the propeller rotational axis.

(3) Absence of propeller aerodynamic forces resulting from the feathering of any single propeller, and for air vehicles 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 3.7.3d.(1) and 3.7.3d.(2) above.

REQUIREMENT RATIONALE (A.3.7.3)

Flutter within the envelope as a result of a failure condition would possibly result in loss of the air vehicle.

REQUIREMENT GUIDANCE (A.3.7.3)

This requirement always applies.

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These design failure cases are those found in MIL-A-8870C(AS) and are the usual ones included in the aeroelastic design failure set. Also these design failure cases include those found in FAR-25.

REQUIREMENT LESSONS LEARNED (A.3.7.3)

Of primary concern are hydraulic failures of control systems, control surface actuator failures including those on flaps and tabs, failures of automatic flight control systems resulting in phase and gain changes, and failures of structure supporting propulsion systems and external stores.

A.4.7.3 Fail-safe stability.

The analyses and tests of 4.7 shall be of sufficient scope to verify that the airframe structure meets the fail-safe stability requirements of 3.7.3.

VERIFICATION RATIONALE (A.4.7.3)

VERIFICATION GUIDANCE (A.4.7.3)

VERIFICATION LESSONS LEARNED (A.4.7.3)

A.3.7.4 Free play of control surfaces and tabs.

Detail design shall assure that normal wear of components, control surfaces and tabs, and actuating systems will not result in values of free play greater than those specified below throughout the service life of the air vehicle. Components having an adequately established wear life may be replaced at scheduled intervals as approved by acquisition activity. However, all replacements shall be included in the wearout replacement budget established for the overall air vehicle. The following free play limits shall apply ___________.

REQUIREMENT RATIONALE (A.3.7.4)

Excessive free play of circuit stiffness designed control surfaces often results in a limited amplitude oscillation which, if uncorrected, may cause a fatigue failure leading to large amplitude flutter and destruction of primary structure.

REQUIREMENT GUIDANCE (A.3.7.4)

If detail design does not provide the recommended free play limits (for control surfaces, tabs, leading and trailing edge flaps, and wingfolds) given below, then non-linear flutter analyses, flutter model wind tunnel tests, fatigue and wear tests, vibration tests, and as necessary, flutter flight tests should be performed to substantiate that values of free play that exceed those listed below are adequate and satisfy the required margins of safety.

a. If a trailing-edge control surface extends outboard of the 75-percent-span station of the main surface, the total free play should be not greater than 0.13 degrees.

b. If a trailing-edge control surface extends outboard of the 50-percent-span station but inboard of the 75-percent-span station of the main surface, the total free play should be not greater than 0.57 degrees.

c. If a trailing-edge control surface is inboard of the 50-percent-span station of the main surface, the total free play should be not greater than 1.15 degrees.

d. The total free play of all-movable control surfaces should be not greater than 0.034 degrees.

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e. If a tab span does not exceed 35 percent of the span of the supporting control surface, the total free play should be not greater than 1.15 degrees.

f. If a tab span equals or exceeds 35 percent of the span of the supporting control surface, the total free play should be not greater than 0.57 degrees.

g. For leading edge flaps, the total free play should be not greater than 0.25 degrees.

h. For a wing fold, the total free play should be not greater than 0.25 degrees.

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, weapons bay doors, and ventral fins (retractable, or jettisonable), the total free play shall not be greater than the applicable value specified above in 3.7.4.a through c.

"Some History of Flutter Criteria" and correspondence with Mr. Mykytow (formerly of the Air Force Flight Dynamics Laboratory), indicates that the free play limits listed above were established based primarily on a series of wind tunnel flutter model tests conducted by the Aircraft Laboratory at Wright-Patterson AFB done in the mid to late 1950's. These model tests included a semispan wing with an unbalanced trailing edge control surface and, later, tests of several all-movable stabilizers. The primary reference for the work on all-movable tails is published in WADC-TR-58-31, but much of the other work was not published but results were used to establish the criteria. These test results indicated that no significant degradation of flutter speed margins of the airplane design would occur if these free play limits were adhered to in service. These free play values were called out in MIL-A-8870(ASG).

REQUIREMENT LESSONS LEARNED (A.3.7.3)

In all cases, tolerances of potential bearing concepts or choices as well as other component manufacturing tolerances and projected wear should be within the established free play limits.

The above Guidance recommended free play limits for all-movable control surfaces are very hard to meet. Free play limits for all-movable control surfaces beyond the recommended are usually justified based on test experience, such as flutter model tests, flight test, etc., and on analyses to some extent. For some air vehicle programs, a free play inspection/maintenance program is established for all-movable control surfaces as well as for other circuit stiffness designed control surfaces.

The maximum free play for the all-movable horizontal tail of an air superiority fighter aircraft is three times the above recommended limit. Flutter model tests and flight testing substantiated these limits. Field and depot inspection/maintenance are performed on these aircraft to maintain these free play limits.

The free play on two early production, all-movable horizontal tails of a fighter aircraft were measured to be two to four times the above recommended limit. Probably, many more of the production aircraft horizontal tails had the same range of free play, but none (except for one out of tolerance surface tail which became unloaded for a certain flight condition) has had any known limit cycle oscillations in flight. For this fighter aircraft, the all-movable horizontal tails are preloaded about the hingeline for essentially all flight conditions. This is the usual case that all-movable horizontal tails on fighter aircraft are preloaded about the hingeline for most or all flight conditions so that the circuit stiffness is fully effective without any effective stiffness reduction due to free play or excursion into the existing free play region where problems may occur.

An all-movable control surface on a missile fluttered with 0.6 degrees of free play.

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The free play limit for all-movable control surface on a tactical missile was established at 0.3 degrees peak to peak. This limit was based on results of a non-linear flutter analyses (only considered structural non-linearity). Although there was a 28% reduction in flutter speed between the linear (zero freeplay) and non-linear (0.3 degrees freeplay) flutter analyses, the non-linear margin of safety exceeded the required 15 percent.

The free play limits for the all-movable canards on two different demonstrator aircraft were established at 0.3 degrees and 0.286 degrees peak to peak. For one of these demonstrator aircraft, a canard free play tracking program was established with frequent periodic checks. The canards on the other aircraft had very large flutter speed margins. No canard flutter problems occurred during the flight test program although during one flight an unusual amount of canard response on one side was noted on the transmitted data which was attributed to free play effects. A ground check indicated excessive free play and a new canard pivot pin was installed to reduce the free play to within limits.

On the other hand, the free play limit for an all-movable vane on a large bomber aircraft was recommended by the contractor to be 0.034 degrees as recommended in the Guidance above. Also, a more stringent requirement, than the above applicable recommended limit, for the free play of the large geared aft rudder segments, is being used on a large cargo aircraft. Since these full span aft rudders are larger surfaces than conventional geared tabs, it was decided to impose a more stringent free play requirement (0.18 degrees peak to peak instead of the above recommended 0.57 degrees). This free play limit was based on successful experience with a similar rudder configuration on a commercial aircraft.

A good discussion of non-linear flutter analyses method is given by Dr. Craig L. Lee in "An Iterative Procedure for Non-linear Flutter Analyses", AIAA Journal, Vol. 24, No. 5, May 1986 page 833. This method only considered structural non-linearity.

A.4.7.4 Free play of control surfaces and tabs.

The analyses and tests of 4.7 shall be of sufficient scope to verify that airframe components, control surfaces and tabs, and actuating systems meets the free play requirements of 3.7.4.

VERIFICATION RATIONALE (A.4.7.4)

VERIFICATION GUIDANCE (A.4.7.4)

VERIFICATION LESSONS LEARNED (A.4.7.4)

A.3.7.5 Environmental effects - aeroelasticity.

The physical characteristics and properties of the control surfaces, tabs, and other components of the airframe shall not be changed by exposure to any natural or man-made environment throughout the service life of the airframe.

REQUIREMENT RATIONALE (A.3.7.5)

Environmentally induced changes of physical characteristics and properties of control surfaces, tabs, and other components of the airframe may result in aeroelastic instabilities within the operational envelope.

REQUIREMENT GUIDANCE (A.3.7.5)

This requirement is always applicable, particularly to those components which are made of metallic or nonmetallic honeycomb, are adhesively bonded, or contain a large percentage of composite material.

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REQUIREMENT LESSONS LEARNED (A.3.7.5)

Flutter incidents have occurred due to the entrapment of water in mass balanced control surfaces which have inadequate drainage or have been inadequately maintained. Adequate drainage of moisture condensate from the aft portion of mass balanced surfaces must be provided or allowances made for possible poor drainage. Also, imperfect sealing of honeycomb surfaces may lead to adverse inertia characteristics. The effect of in-service fuel density variations should be considered for aircraft with flutter characteristics sensitive to fuel quantity.

A.4.7.5 Environmental effects - aeroelasticity.

The analyses and tests of 4.7 shall be of sufficient scope to verify that the air vehicle components are in compliance with the environmental effects requirements of 3.7.5.

VERIFICATION RATIONALE (A.4.7.5)

VERIFICATION GUIDANCE (A.4.7.5)

VERIFICATION LESSONS LEARNED (A.4.7.5)

A.3.8 Required structure survivability - nuclear. (___).

a. The threat environment, resultant threat effects, air vehicle orientation, configuration, and mission/operating conditions are defined in ______________.

b. The gust and overpressure loads are limit loads. The damage tolerance requirements of 3.12 are applicable.

c. The operational survivability and hardness requirements for structural integrity of the airframe, threat damage tolerance, structural shielding, and structural provisions for nonstructural shielding as a result of exposure to the specified nuclear environment are:

(1) Primary structure ______________________.

(2) Flight control surfaces ______________________.

(3) Windshield/Canopy ______________________.

(4) Other ______________________.

d. Post damage availability. For combat damaged airframe structure and successful return of the air vehicle, the damaged structural parts shall be capable of being repaired, replaced, or interchanged with fully serviceable parts within the air vehicle post combat availability time specified in _____________________.

REQUIREMENT RATIONALE (A.3.8)

This requirement reflects the ability of the structure to perform effectively in a combat environment and its contribution to overall air vehicle mission completion capability. A balanced approach must be used to achieve the desired protection in varied mission roles. Properly designed air vehicles, including their structure, can increase combat effectiveness by lowering the probability of detection with resultant higher number of air vehicles reaching the target objective and completing the mission; increased capability to avoid or negate the threat if detected/tracked; and increased ruggedness (damage tolerance) to threat effects, thus providing a higher probability of returning from the encounter to be subsequently repaired and used again.

REQUIREMENT GUIDANCE (A.3.8)

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If applicable, proceed as follows:

a. Insert reference to the appropriate document which defines the system combat mission parameters (i.e., threats, threat effects, exposures, air vehicle configuration, operating envelopes, etc.). Upon determination of the appropriate system-level values, those values will normally be included in the system specification or in an appendix thereto. Therefore, the reference inserted here will generally be to the system specification and an appropriate paragraph or appendix number. In some cases this reference may be to a separately numbered document that contains the quantified parameters.

b. No entry required.

c. The survivability requirements related to airframe structure are defined based on allocations from the system-level parameters for mission completion in a combat environment. The ability of the air vehicle to complete its mission is dependent upon its capability to avoid damage (i.e., threat avoidance) or to accept damage (i.e., damage tolerance) up to some level and continue to carry flight loads, possibly at a reduced load factor.

(1) Threat avoidance. One aspect of threat avoidance is the overall air vehicle observables or signatures. Therefore, the contribution of the structure to these signatures (radar cross section, infrared, visual, aural) must be addressed and requirements for reduction or control of the signature levels defined in consonance with the system-level mission completion requirements.

(2) Threat-induced damage tolerance. The structure is vulnerable to any damage mechanisms which reduce the load carrying strength of structural components (including attach points), result in change or misalignment of load paths, or increase (including transient impulses) the load on the structure. Primary nuclear damage/kill mechanisms which can cause these damage modes are blast and thermal energy. The structure may also be vulnerable to secondary damage/kill mechanisms such as fire. Fuel tank evaluation should include consideration of fire probability under given threat. Also, a cost/weight evaluation should be made of tank inerting and secondary structural modification for suppressing hydrodynamic pressure when appropriate.

Key variables in specifying survivability requirements for structure must consider the specified threat(s) and damage mechanisms. The damage/kill criteria for structure may include definition of the required residual strength capability after the damage occurrence or required mission performance capabilities that must remain after structure is damaged. An alternative approach is to state a specific damage size of level for use in developing the detailed structural design criteria.

d. Insert reference to appropriate document system combat mission parameters - see 3.8.a Guidance. Some considerations for structural requirements relative to post combat availability are:

(1) The airframe structure shall be as damage tolerant as practical to minimize the probability of loss due to threat-induced damage. Additionally, the structure shall incorporate those features that will enhance rapid repair of combat damage.

REQUIREMENT LESSONS LEARNED (A.3.8)

Starting with and since WW II, each period of hostility has prompted major concerns about combat aircraft attrition rates. Programs were initiated to increase survivability (mission completion/effectiveness) of combat aircraft. These programs were primarily directed towards

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short-term, quick payoff modifications to operational and in production aircraft. Due to their nature, the modifications were generally costly, added unnecessary weight, and provided only marginal protection against real-world threats. Once hostilities cease, potential attrition rates are no longer considered to have high priority in new aircraft designs. Many of the deficiencies in design (causing increased attrition rates) can be eliminated or at least minimized if a concerted effort is made at the very start to incorporate proven survivability features into the design of air vehicles (structures) at a time when appropriate trades can be made between effectiveness gained vs performance and cost penalties.

Design phase. The criteria developed for the nuclear weapon effects should give a design that produces a balanced, hardened airframe which will not overly penalize the airframe in terms of cost, weight, or range.

Development phase. Thermal radiation causes a rapid rise in temperature on the outer surface of the airframe and produces severe skin buckling of metal and debonding of non-metal structure. The outer surface supporting structure is affected to a lesser degree due to the air gaps separating the outer skin from ribs, frames, and stringers. The exterior surface coating such as paint increases its ability to withstand the thermal radiation effects of a nuclear detonation. The computer program TRAP can predict with a reasonable degree of accuracy the response of the structure to thermal radiation.

The overpressure influences the secondary elements of the structure, namely, the skin panels, the stringers, and the frames, particularly on the fuselage. The loading consists of a high reflected pressure which decays in a few milliseconds, but can cause permanent deformation buckling of skin panels.

The computer program NOVA-2 can predict with a reasonable degree of accuracy the response of the structure due to overpressure from a nuclear detonation. The changes in angle of attack and dynamic pressure of the blast waves causes highly transient gust loads on the airframe similar to atmospheric gusts. These gust loads primarily influence major structural components of an aircraft such as wings, fuselage, nacelles, external stores, horizontal, and vertical tails. The computer program VIBRA-6, those developed by BMAC and other aircraft companies can predict the structural responses of these components due to a gust from a nuclear detonation.

Studies run by BMAC and the USAF show that there is a large variation in the gust and overpressure loads predicted and that the gust and overpressure should be treated as limit load to assure mission completion. The limit load is multiplied by the factor of uncertainty of 1.5 and compared to ultimate allowables similar to any other design load condition.

Testing. Special coupon testing on nonmetallic structure will be cost effective when determining radiation influence levels that result in debonding. These tests can be performed at the ASD Quartz Lamp Facility. When large component testing is required for nuclear effects due to thermal radiation, overpressure, and gusts, facilities such as TRS and the Thunder Pipe at Kirtland Air Force Base, as well as the White Sand Test Facilities, are available.

A.4.8 Required structure survivability - nuclear. (___)

Analyses shall be performed to verify compliance of the airframe structure with the structural survivability requirements of 3.8, along with developmental tests.

a. Analyses. A vulnerability analysis shall be performed using ________________. Stress analyses and other airframe analyses shall be expanded as necessary to show compliance of the structure with the requirements of 3.8 and for use as a data base for input to the vulnerability analysis.

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b. Tests. Blast tests and other appropriate nuclear weapons effects and structure response tests shall be conducted whenever the data base is insufficient to demonstrate verification of the requirements of 3.8. Development, proof, static, damage tolerance, and other airframe tests shall be used, or expanded as necessary, to support this verification and show compliance of the structure with the requirements of 3.8.

c. Combat damage repair. The results of the above analyses and tests shall be used as a basis for the combat damage repair analysis to determine and verify the contribution of structure damage repair to meeting the air vehicle post combat damage availability time requirements.

VERIFICATION RATIONALE (A.4.8)

Analyses (vulnerability and repair), development, and component testing are required to verify that the structure possesses the required characteristics to perform in a combat environment for mission completion and has the required repairability characteristics.

VERIFICATION GUIDANCE (4.8)

Define the methods and approaches to be used in subparagraph a. or insert the reference which defines the approaches and methods to be used. For example, JTCG/AS-75-V-008.

VERIFICATION LESSONS LEARNED (A.4.8)

A.3.9 Required structure survivability - nonnuclear. (____).

a. The threat environment, resultant threat effects, air vehicle orientation, configuration, and mission/operating conditions are defined in ______________________.

b. The damage tolerance requirements of 3.12 are applicable.

c. The operational survivability requirements for structural integrity of the airframe, threat damage tolerance, and structural provisions for nonstructural shielding and armor as a result of exposure to the specified nonnuclear environment are:

(1) Primary structure ______________________.

(2) Flight control surfaces ______________________.

(3) Windshield/Canopy ______________________.

(4) Other ______________________.

d. Post damage availability. For combat damaged airframe structure and successful return of the air vehicle, the damaged structural parts shall be capable of being repaired, replaced, or interchanged with fully serviceable parts within the air vehicle post combat availability time specified in ______________________.

REQUIREMENT RATIONALE (A.3.9)

This requirement reflects the ability of the structure to perform effectively in a combat environment and its contribution to overall air vehicle mission completion capability. A balanced approach must be used to achieve the desired protection in varied mission roles. Properly designed air vehicles, including their structure, can increase combat effectiveness by lowering the probability of detection with resultant higher number of air vehicles reaching the target objective and completing the mission, increased capability to avoid or negate the threat if detected/tracked, and increased ruggedness (damage tolerance) to threat effects, thus providing a higher probability of returning from the encounter to be subsequently repaired and used again. The ultimate purpose of this requirement is to lower attrition rates which in turn

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translates to fewer air vehicles required for mission accomplishment, or more air vehicles available for other targets.

REQUIREMENT GUIDANCE (A.3.9)

If the paragraph is applicable, proceed as follows:

a. Insert reference to the appropriate document which defines the system combat mission parameters (i.e., threats, threat effects, exposures, air vehicle configuration, operating envelopes, etc.). Upon determination of the appropriate system-level values, those values will normally be included in the system specification or in an appendix thereto. Therefore, the reference inserted here will generally be to the system specification and an appropriate paragraph or appendix number. In some cases, this reference may be to a separately numbered document that contains the quantified parameters.

b. No entry is required.

c. The survivability requirements related to airframe structure are defined based on allocations from the system-level parameters for mission completion in a combat environment. The ability of the air vehicle to complete its mission is dependent upon its capability to avoid damage (i.e., threat avoidance) or to accept damage (i.e., damage tolerance) up to some level and continue to carry limit loads, possibly at a reduced load factor.

d. Insert reference to appropriate document defining system combat mission parameters--see 3.9.a Guidance. Some considerations for structural requirements relative to post combat availability are:

(1) The airframe structure shall be as damage tolerant as practical to minimize probability of loss due to threat-induced damage. Additionally, the structure shall incorporate those features that will enhance rapid repair of combat damage, especially for forward area (limited capability) maintenance/repair operations.

(2) The selection of materials, type of construction, and structural configuration shall consider the type and extent of damage that can result from the specified threat effects. Structural criteria must then address the time, amount of effort, skill levels and costs required to effect combat damage repairs, with the goal being to minimize repair time and requirements for personnel, types of spar parts, special tools, facilities, fixtures, master jigging, etc., not indigenous to maintenance operations under wartime conditions. Accessibility shall be a prime feature to reduce air vehicle downtime due to combat damage repair.

(3) Where the extent of repair is beyond the operational unit's capability, structural criteria shall consider removal and replacement concepts and maximum interchangeability with minimum maintenance effort.

(4) The use of nonmetallic or composite structure shall be carefully analyzed to establish the means by which combat damage can be repaired rapidly or damaged sections removed/replaced under wartime operational maintenance conditions.

(5) Materials and protective coatings shall be selected so that adequate corrosion prevention/control can be maintained following repair of combat damage.

(6) Predesigned and prefabricated repair concepts in kit form shall be considered.

(7) For composites, particular emphasis must be placed on the issue of battle damage from weapons since the containment of this damage may well dictate the design

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configuration. In addition to a composite design that can contain weapons damage, the design must also be repairable from that damage to maintain operational readiness. For many composite structures, the damage tolerance requirements will determine the allowable strain. However, the battle damage requirements are likely to influence the composite structure arrangement. For example, the need to contain battle damage to prevent catastrophic loss of the aircraft may well dictate the use of fastener systems and/or softening strips. The battle damage threat must be examined in the initial phase of the design. A fall out capability for battle damage based on configurations that meet all other requirements may not be adequate.

REQUIREMENT LESSONS LEARNED (A.3.9)

Starting with and since WW II, each period of hostility has prompted major concerns about combat aircraft attrition rates. Programs were initiated to increase survivability (mission completion/effectiveness) of combat aircraft. These programs were primarily directed towards short-term, quick-payoff modifications to operational and in production aircraft. Due to their nature, the modifications were generally costly, added unnecessary weight and provided only marginal protection against real-world threats. Once hostilities cease, potential attrition rates are no longer considered to have high priority in new aircraft designs. Many of the deficiencies in design (causing increased attrition rates) can be eliminated or at least minimized if a concerted effort is made at the very start to incorporate proven survivability features into the design of air vehicles (structures) at a time when appropriate trades can be made between effectiveness gained vs performance and cost penalties.

A.4.9 Required structure survivability - nonnuclear. (___)

Analyses shall be performed to verify compliance of the airframe structure with the structural survivability requirements of 3.9, along with developmental tests.

a. Analyses. A vulnerability analysis shall be performed using ________________. Stress analyses and other airframe analyses shall be expanded as necessary to show compliance of the structure with the requirements of 3.9 and for use as a data base for input to the vulnerability analysis.

b. Tests. Where the data base is insufficient to obtain meaningful verification results by analyses, ballistic tests and other appropriate nonnuclear weapons effects and structure response tests shall be conducted to show that the airframe structure complies with the requirements of 3.9. Development, proof, static, damage tolerance, and other airframe tests shall be used, or expanded as necessary, to support this verification and show compliance of the airframe structure with the requirements of 3.9. In addition, other tests may be required by statutory requirements, e.g. the Live Fire Test legislation.

c. Combat damage repair. The results of the above analyses and tests shall be used as a basis for the combat damage repair analysis to determine and verify the contribution of structure damage repair to meeting the air vehicle post combat damage availability time requirements.

VERIFICATION RATIONALE (A.4.9)

Analyses (vulnerability and repair), development, and component testing are required to verify that the structure possesses the required characteristics to perform in a combat environment for mission completion and has the required repairability characteristics.

VERIFICATION GUIDANCE (A.4.9)

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Define the methods and approaches to be used in subparagraph 4.9.a. or insert the reference which defines the approaches and methods to be used. For example, JTCG/AS-75-V-008.

VERIFICATION LESSONS LEARNED (A.4.9)

R&D programs have been and are being conducted to develop criteria and assessment methods for structural survivability. These programs include related ballistic testing and detailed investigation/analysis of actual combat damage/loss experience, primarily from Southeast Asia. From this, damage prediction, residual strength prediction, residual stiffness prediction and other prediction models are available, along with pertinent criteria, in the following (not all inclusive) documents: AFFDL-TR-68-105, AFFDL-TR-70-116, AFFDL-TR-74-50, AFFDL-TR-75-73, AFFDL-TR-78-29, and JTCG/AS-75-V-008.

A.3.10 Strength.

The airframe strength shall be adequate to provide the operational and maintenance capability required commensurate with the general parameters of 3.2 and 3.3 without detrimental deformations of 3.2.13 at 115 percent limit or specified loads and without structural failure at ultimate loads. The airframe strength shall also be adequate to meet the requirements of 3.1.2.

REQUIREMENT RATIONALE (A.3.10)

Adequate airframe strength must be provided not only for safety of flight, for landings and for maintenance functions, but also to permit full operational capability of the air vehicle to perform its required missions. An understrength airframe impairs the mission potential of the air vehicle, since it must be restricted during its operations.

REQUIREMENT GUIDANCE (A.3.10)

The structure shall have sufficient strength so that it can carry limit loads without detrimental deformations which would interfere with its safe operational and maintenance capabilities. The structure must be able to react ultimate loads without rupture or collapsing failure.

REQUIREMENT LESSONS LEARNED (A.3.10)

A.4.10 Strength.

Inspections, analyses, and tests shall be performed which encompass all critical airframe loading conditions to verify that:

a. Detrimental airframe structural deformations including delaminations do not occur at or below 115 percent of design limit load.

b. Rupture or collapsing failures of the airframe structure do not occur at or below ultimate loads.

VERIFICATION RATIONALE (A.4.10)

Inspections, analytical strength calculations, and tests are needed to show that the airframe structure can withstand the loads expected in service usage. In most cases ultimate load tests and associated test data can only be attained through ground tests under laboratory conditions.

VERIFICATION GUIDANCE (A.4.10)

In addition to the analytical strength calculations, it has been conventional to conduct strength proof tests to determine if detrimental deformations will occur in the airframe. Static tests are typically employed to verify that the airframe will sustain ultimate loads without failure.

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As for metal structures, the strength analyses for composites are inexorably linked to the design development tests. For support of these analyses it is recommended that the design development testing consist of "building blocks" ranging from coupons to elements, to subcomponents and finally components.

VERIFICATION LESSONS LEARNED (A.4.10)

A.3.10.1 Material properties.

Strength related material property requirements are contained in 3.2.19.1.

REQUIREMENT RATIONALE (A.3.10.1)

This requirement references the basic material properties requirements which are in one place and cover all of the structures disciplines requirements.

REQUIREMENT GUIDANCE (A.3.10.1)

Check to see that all strength related material properties requirements are included in 3.2.19.1.

REQUIREMENT LESSONS LEARNED (A.3.10.1)

A.4.10.1 Material properties.

Strength related material property verification requirements are contained in 4.2.19.1.

VERIFICATION RATIONALE (A.4.10.1)

This requirement references the basic material properties verification requirements which are in one place and cover all of the structures disciplines verifications.

VERIFICATION GUIDANCE (A.4.10.1)

Check to see that all strength related material properties verification requirements are included in 4.2.19.1.

VERIFICATION LESSONS LEARNED (A.4.10.1)

A.3.10.2 Material processes.

Strength related material processing requirements are contained in 3.2.19.2.

REQUIREMENT RATIONALE (A.3.10.2)

This requirement references the basic material processes requirements which are in one place and cover all of the structures disciplines requirements.

REQUIREMENT GUIDANCE (A.3.10.2)

Check to see that all strength related material process requirements are included in 3.2.19.2.

REQUIREMENT LESSONS LEARNED (A.3.10.2)

A.4.10.2 Material processes.

Strength related material processing verification requirements are contained in 4.2.19.2.

VERIFICATION RATIONALE (A.4.10.2)

This requirement references the basic material processes verification requirements which are in one place and cover all of the structures disciplines verifications.

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VERIFICATION GUIDANCE (A.4.10.2)

Check to see that all strength related material processes verification requirements are included in 4.2.19.2.

VERIFICATION LESSONS LEARNED (A.4.10.2)

A.3.10.3 Internal loads.

Internal loads of structural members within the airframe shall react the external loads generated by the air vehicle during operation and maintenance functions. Load paths shall be configured and controlled to be as direct as practical through the proper locating of primary structural members, selecting of materials, and sizing of members. The effects of panel buckling, material yield, and fastener tolerances on internal load distributions shall be considered.

REQUIREMENT RATIONALE (A.3.10.3)

Efficiencies in configuring load paths, in sizing of members, and in selecting materials, are contingent upon having available the associated internal loads values. Also, the internal loads on structural members must be known prior to writing strength analyses and calculating margins of safety. Direct load paths provide highly reliable structures, while indirect load paths result in complex reactions, inefficient load paths, and heavier structural weights.

REQUIREMENT GUIDANCE (A.3.10.3)

Internal loads on all structural members are typically determined for critical loading conditions. Detailed internal loads are identified as limit or design ultimate loads. For landing gears and other beam-column members, ultimate internal loads are calculated by multiplying the factor of safety times limit internal loads, which necessarily include secondary moment effects resulting from the strut's limit load bending deflections. Recommended load paths and design guides are described in Chapter 2 of AFSC DH 2-1. Internal loads may be determined using classical methods such as those described in "Analysis and Design of Flight Vehicle Structures", "Airplane Structure", and "Aircraft Structures", or using computer finite element computer programs.

REQUIREMENT LESSONS LEARNED (A.3.10.3)

A.4.10.3 Internal loads.

Validity of the internal loads and configurations of efficient load paths required in 3.10.3 shall be verified by inspections, analyses, and tests.

VERIFICATION RATIONALE (A.4.10.3)

Internal loads must be verified to assure structural integrity of the airframe.

VERIFICATION GUIDANCE (A.4.10.3)

The validity of internal loads are conventionally verified by applicable laboratory tests of 4.10.5 and subparagraphs, thereof. The efficiency of load path configurations may initially be determined by reviewing assembly drawings, installation drawings, and the structural description report; however, laboratory tests provide final verification.

VERIFICATION LESSONS LEARNED (A.4.10.3)

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A.3.10.4 Stresses and strains.

Stresses and strains in airframe structural members shall be controlled through proper sizing, detail design, and material selections to satisfactorily react all limit and ultimate loads. In laminated composites, the stresses and ply orientation are to be compatible and residual stresses of manufacturing are to be accounted for, particularly if the stacking sequence is not symmetrical.

REQUIREMENT RATIONALE (A.3.10.4)

It is necessary to control airframe stresses and strains in order to satisfactorily accomplish material selection and part sizing. Stresses and strains must be known prior to determining margins of safety. In addition, stresses and strains must be known for salvage evaluation of any production damaged parts, strength evaluation of engineering change proposals, airframe structural modifications, and evaluation of in-service, structural damage and making of repairs as required.

REQUIREMENT GUIDANCE (A.3.10.4)

Stresses and strains on an airframe's component members for critical loads that encompass the maximum loading conditions need to be determined. The structure must have the ability to support critical loads. Load paths of adequate strength need to be established.

REQUIREMENT LESSONS LEARNED (A.3.10.4)

4.10.4 Stresses and strains.

Validity of stresses and strains in airframe structural members complying with the requirements of 3.10.4 shall be verified by inspections, analyses, and tests.

VERIFICATION RATIONALE (A.4.10.4)

Stresses and strains and stress and strain distributions must be verified to assure that adequate structural integrity exists in the airframe for the intended service usage.

VERIFICATION GUIDANCE (A.4.10.4)

The validity of stress and strain calculations must be verified.

a. Validation information includes descriptions of the structural components, the type of construction, arrangement, material, location of load carrying members, and other pertinent data.

b. Also needed for particular components are maximum shears, bending moments, torques and, where appropriate, thermal gradients. Tables of minimum margins of safety are needed.

c. Stresses and strains are normally determined on the basis of ultimate loads, and sometimes stresses and strains are determined based on limit loads which are more critical for material yield strength. Margins of safety need to be established. Margins of safety calculated by computer methods may not adequately account for joint attachment strength, combined loadings, local discontinuities, beam-column effects, crippling, panel buckling, etc. and separate hand-analyses may be needed.

d. Measurements of stress and strain distributions on major components obtained from static tests need to be correlated with analytical distributions.

e. Thermal stresses and strains are typically determined for structures that experience significant heating or cooling whenever expansion or contraction is limited by external or

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internal constraints. Thermal stresses and strains are combined with concurrent stresses produced by other load sources in a conservative manner.

VERIFICATION LESSONS LEARNED (A.4.10.4)

A.3.10.4.1 Fitting factor.

For each fitting and attachment whose strengths are not proven by limit and ultimate load tests in which actual stress conditions are simulated in the fitting and surrounding structure, the design stresses values shall be increased in magnitude by multiplying these loads or stress values by a fitting factor. This fitting factor and the conditions for its use are as follows: __________________.

REQUIREMENT RATIONALE (A.3.10.4.1)

It is necessary to use a fitting factor, since many uncertainties exist in regard to stress distributions within fittings. Manufacturing tolerances are such that bolts within a pattern rarely fit the holes perfectly and small variations in dimensions may affect stress distributions. Failures are more likely to occur at fittings connected to members than in the members themselves because of local stress concentrations at the connections, slight eccentricities of the attachments, or more severe vibration conditions.

REQUIREMENT GUIDANCE (A.3.10.4.1)

A fitting factor equal to 1.15 is applicable not only for the fitting and attachment but for all bolted and welded joints and for the structure immediately adjacent to the joints. Some contractors use a factor as high as 1.5 for tension joints. However, it is not necessary to use the fitting factor for continuous lines of rivets installed at sheet-metal joints. The fitting factor in the strength analysis can be multiplied by either the load or stress, whichever is convenient. Fitting lug thicknesses and edge distance must be sufficient to account for the most adverse tolerances and allow for future repairs such as reaming, inserting a bushing, or replacement of an existing bushing with an oversize bushing. The guidelines in DN 4B1 of AFSC DH 1-1 are applicable to fittings. The fitting design must also account for angular misalignment.

REQUIREMENT LESSONS LEARNED (A3.10.4.1)

Major structural elements on aircraft periodically require repair for attachment of pylons, landing gear components, loading ramps, underfloor fittings, etc. Many existing fittings in current aircraft do not have sufficient, remaining lug material to permit rebushing repair with oversize bushings after reaming the score-damaged lug holes. Since, in many cases, the repair cannot be accomplished without degrading the capability of the fitting below the initial system design requirement, costly and time-consuming replacement is required.

A.4.10.4.1 Fitting factor.

Fitting factors shall be shown to be in compliance with the requirements of 3.10.4.1 by analyses.

VERIFICATION RATIONALE (A.4.10.4.1)

The verification of the fitting factors used shall be accomplished.

VERIFICATION GUIDANCE (A.4.10.4.1)

Whenever component or complete airframe static tests to limit and ultimate loads are not planned, the strength analyses report typically incorporates fitting factors for fittings and applicable joints.

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VERIFICATION LESSONS LEARNED (A.4.10.4.1)

As stated in AFSC DH 1-2, ". . . fittings are known to have a relatively high failure rate, the amount of weight added by this [1.15] factor is small for the increase obtained in structural integrity."

A.3.10.4.2 Bearing factor.

When a bolted joint with clearance (free fit) is subjected to relative rotation under limit load or shock and vibration loads, the design stress values shall be increased in magnitude by multiplying a bearing factor times the stress values. This bearing factor and the conditions for its use are as follows: _______________.

REQUIREMENT RATIONALE (A.3.10.4.2)

Bolts loaded by shock or vibration, such as in landing gears, tend to hammer back and forth in bolt holes. This hammering may enlarge the bolt holes enough to produce failure of the part if the bearing stresses are high.

REQUIREMENT GUIDANCE (A.3.10.4.2)

A bearing factor of 2.0 or more is applicable; however, when there is no motion between bushing and lug, the bearing factor is one. The bearing factor must be multiplied by the safety factor of 1.5 but need not be multiplied by the 1.15 fitting factor. In lieu of bearing factors, allowable bearing properties which have acceptable reduced values to account for bearing factors may be used. The design guidelines for bushings may be found in Chapter 6 of AFSC DH 2-1.

REQUIREMENT LESSONS LEARNED (A.3.10.4.2)

A.4.10.4.2 Bearing factor.

Bearing factors shall be shown to satisfy the requirements of 3.10.4.2 by analyses.

VERIFICATION RATIONALE (A.4.10.4.2)

The verification of the bearing factors used shall be accomplished.

VERIFICATION GUIDANCE (A.4.10.4.2)

The use of bearing factors or acceptable reduced bearing allowables is typically shown in the strength analyses report.

VERIFICATION LESSONS LEARNED (A.4.10.4.2)

A.3.10.4.3 Castings.

Castings shall be classified and inspected, and all castings shall conform to applicable process requirements. A casting factor of ________ shall be used. The factors, tests, and inspections of this section must be applied in addition to those necessary to establish foundry quality control. The use of castings or C/Hiped parts for primary or critical applications or castings with a casting factor less than 1.33 shall require successful completion of a developmental and qualification program approved by the procuring agency.

REQUIREMENT RATIONALE (A.3.10.4.3)

REQUIREMENT GUIDANCE (A.3.10.4.3)

REQUIREMENT LESSONS LEARNED (A.3.10.4.3)

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A.4.10.4.3 Castings.

All castings shall be shown to satisfy the casting factor requirements of 3.10.4.3 by analysis. Non-critical castings with a casting factor of 1.33 or greater require no special testing in excess of the requirements of 4.10.5.2. Critical castings, castings used in primary structure, or castings with a casting factor less than 1.33 must meet the following requirements:

a. Receive 100 percent inspection by visual and magnetic particle or penetrant or approved equivalent non-destructive inspection methods.

b. Three sample castings from different lots must be static tested and shown to meet the deformation requirements of 4.10.a. at a load of 1.15 times the limit load, and meet the ultimate strength requirements of 4.10.b. at a load of the casting factor times the ultimate load. After successful completion of these tests, a casting factor of greater than 1.00 need not be demonstrated during the full scale static test.

c. The castings must be procured to a specification that guarantees the mechanic properties of the material in the casting and provides for demonstration of these properties by test coupons cut from cut-up castings on a sampling basis and from test tabs on each casting.

d. Meeting the analytical requirements of 3.10.4.4 without a casting factor.

e. Meet the service life requirements of 3.2.14 for both crack initiation and crack growth for flaws representative of the casting and manufacturing process.

VERIFICATION RATIONALE (A.4.10.4.3)

VERIFICATION GUIDANCE (A.4.10.4.3)

VERIFICATION LESSONS LEARNED (A.4.10.4.3)

A.3.10.4.4 High variability structure.

Due to the nature of some structural designs or materials, high variability may be encountered around the nominal design. Such design features must have a minimum level of structural integrity at the acceptable extremes of dimensions, tolerances, material properties, processing windows, processing controls, end or edge fixities, eccentricities, fastener flexibility, fit up stresses, environments, manufacturing processes, etc. For the critical combinations of these acceptable extremes, the structure must have no detrimental deformation of the maximum once per lifetime load of 3.2.14.6 and no structural failure at 125 percent of design limit load and meet the requirements of 3.7.1. This requirement is in addition to the requirements of 3.10. Examples of such structure are stability critical compression structure, stability critical panels, some composites, resin transfer molded composite parts, castings with low castings factors, manufacturing critical parts, etc.

REQUIREMENT RATIONALE (A.3.10.4.4)

Historically, the analytical baseline criteria is nominal dimensions, nominal blue print eccentricities, and statistically reduced material allowables. However, a minimal level of structural strength is required for all structural members which meet the acceptable extreme range of blue print dimensions, processing windows, material property specifications, and manufacturing tolerances. This is required for safety of flight structure since these parts could easily exist on the aircraft since they are per blueprint and per process specifications.

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REQUIREMENT GUIDANCE (A.3.10.4.4)

This should not normally be a design consideration for most conventional designs and materials since the normal variation in material properties, fabrication, processes, and manufacturing allow the design to meet this requirement. Therefore, the primary focus of this requirement should be to identify those critical dimensions or processes that need extra control or tighter tolerances. This requirement also provides assurance that new materials, processes, or design concepts are sufficiently mature to provide a stable baseline.

REQUIREMENT LESSONS LEARNED (A.3.10.4.4)

Many low cost production initiatives involve opening up the process windows, tolerances, or specification. Designs that are qualified using nominal dimensions and statistical materials allowables could have safety of flight parts that are significantly understrength while fully complying with all blueprints, processes, and specifications.

A state of the art fighter is using HIPped castings with thin walls and a casting factor of 1.00 in safety of flight applications. The nominal thickness of these thin walls was 0.08, but the actual range of casting wall thicknesses came out from 0.05 to 0.12. The casting vendor wanted the thickness tolerances opened up to allow this wide variations. Since this variation in wall thickness would allow up to a 38% understrength condition to exist, the contractor agreed to design to minimum thickness x 1.10 while opening up the thickness tolerance to increase casting yield.

The strength of some critical structure such as stability critical panels varies with the square of the thickness. If the minimum thickness is not controlled either by callout or tighter tolerance, a significant understrength condition could exist while still being "per blueprint."

A.4.10.4.4 High variability structure.

High variability structure shall be shown to satisfy the requirements of 3.10.4.4 by analyses. These analyses should be conducted using at least the following considerations in the critical combinations of these acceptable extremes:

a. Minimum thickness or area.

b. Critical dimensions such as longest column length.

c. "A" allowables for all properties including E or lowest guaranteed properties or lowest incoming inspection limits, whichever are the most critical.

d. Critical allowable tolerance buildup, eccentricities, or fit up stresses.

e. Properties that result from the edges or corners of the processing windows or processing controls.

f. Minimum edge or end fixities unless large scale test results are available for the same configuration, then minimum test derived edge or end fixities may be used.

g. Critical range of fastener flexibilities.

h. Other _______________.

VERIFICATION RATIONALE (A.4.10.4.4)

The verification of this requirement shall be accomplished by analyses considering at least the identified considerations as well as any other critical items.

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VERIFICATION GUIDANCE (A.4.10.4.4)

The primary output of this requirement should be the identification and control of critical dimensions and processes that need extra control. Minimal additional analyses should be required if this requirement is properly implemented.

VERIFICATION LESSONS LEARNED (A.4.10.4.4)

A.3.10.5 Static strength.

Sufficient static strength shall be provided in the airframe structure for reacting all loading conditions loads without degrading the structural performance capability of the airframe. Sufficient strength shall be provided for operations, maintenance functions, and any tests that simulate load conditions, such that:

a. Detrimental deformations, including delaminations, shall not occur at or below 115 percent of limit loads, or during the tests required in 4.10.5.3 and 4.10.5.4. The deformation requirements of 3.2.13 apply.

b. Rupture or collapsing failures shall not occur at or below ultimate loads.

c. All structure shall be designed to nominal dimensional values or 110 percent of minimum values, whichever is less.

d. Bonded structure shall be capable of sustaining the residual strength loads of 3.12.2 without a safety of flight failure with a complete bond line failure or disbond.

REQUIREMENT RATIONALE (A.3.10.5)

The mission potentials of the air vehicle must not be compromised by lack of airframe static strength. Excessive deflections may not only produce deleterious aerodynamic or aeroelastic effects, but may cause binding interferences between hinge connected and adjacent structures as well. Exterior surface buckles, especially those that are permanent, may produce undesirable aerodynamic characteristics.

REQUIREMENT GUIDANCE (A.3.10.5)

Ultimate stresses are not to be exceeded at ultimate loads. Calculated deflections and surface buckling deformations need to be coordinated through responsible aerodynamic and aeroelastic disciplines for evaluating possible performance penalties.

For composites, the allowable for a given flight condition shall be based on the temperature appropriate for that flight condition combined with the most critical of the range of possible moisture conditions. The factor of uncertainty to be used in the application of the allowables derived above is 1.5. Since the strength of a composite structure is inherently dependent on the lay up of the laminate, geometry, and type of loading, the "B" basis allowable must include these factors. However, the cost of a test program involving the number of complex components necessary to determine the "B" basis allowable could be prohibitive. An acceptable approach is to determine the "B" basis allowable from coupon data representative of the lay up and loading.

REQUIREMENT LESSONS LEARNED (A.3.10.5)

Case histories of static testing programs have been assembled for a number of Air Force aircraft. The static test programs surveyed are typical of all past programs. All production aircraft were static tested in a timely manner, using very low numbered airframes. Some delays were experienced when major structural failures occurred, but these do not reflect on the timeliness of the overall programs. For the aircraft surveyed from 1950-1970, the only aircraft

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not experiencing major failures were direct outgrowths of earlier models which had gone through complete static test programs; the other tested aircraft are known to have suffered major test failures.

Comparison of Air Force and FAA structural test requirements is often made. Despite the fact that commercial transports are flown conservatively, are designed to low nominal stress levels, and there are no complete ultimate load test requirements by the FAA, an increasing number of manufacturers are conducting ultimate load tests. It should be noted that the size and expense of these airframes has not deterred the manufacturers from recognizing the benefits of such tests. The primary goal has been for the purpose of determining growth potential.

Historically, increased mission requirements have been levied on most military aircraft after entering service. This usually means increased fuel or armament with associated weight increase. At the same time, it is desired to minimize structural capability degradation. It is, therefore, of prime importance to know the growth potential in the structure or, precisely, what limitations may have to be imposed. A proof test program cannot determine growth potential. This can only be accomplished by complete, ultimate load tests, including judiciously-selected, failing load tests.

Efforts have usually been made to discover structural deficiencies by static tests at the earliest possible time, in order to minimize the impact of retrofit changes. Most major, static test failures have necessitated subsequent engineering changes. These changes were usually incorporated within early, follow-on production aircraft with minimal retrofit effort required. However, when major structural redesign efforts have been initiated in programs, concurrent with production adjustments, static tests have had to be rescheduled. Consequently, decisions have had to be made on retrofitting previously produced aircraft with whatever changes the test showed to be necessary.

Almost without exception, past static test programs have revealed a variety of structural deficiencies or related problem areas. Table XVI and figure 25 are taken from "Structural Testing for Aircraft Development" to show failure trend data and reinforce the basic requirement for conducting static tests at the earliest possible time in the production or preproduction cycle.

Additional information and data from "Analysis of the Premature Structural Failures in Static Tested Aircraft" are the results of a study of static tests performed at WPAFB from 1940 to 1976. See tables XVII through XXII. The early tests (1940-1948) represent 115 airplanes, and the later tests (1950-1976) represent 22 airplanes. Many different types of airframes were tested in the 1940s as follows: fighter-32, trainer-22, glider-20, bomber-14, cargo-12, attack-8, liaison-4, observation-2, and one helicopter. Because of the war demand for metals, considerable use of wood/plywood in many airplanes resulted. After the war, from 1950 and on, the use of wood/plywood was phased out completely as far as primary structures were concerned. A review of the data indicates that the type of airplane and material used do not bias or disproportionately influence the distribution of failures. The following is a discussion of the test results from the viewpoint of airplane first failure and major component first failure. Other parts of this handbook have reviewed the test results from the viewpoint of distribution of structural failures, considering only those components which failed, including all retests of those components.

The data presented in figure 26 is from four groupings of the test results. Two of the groups are for first failures of a major component of each airplane. The next two groups are for first failures of each of the five major components of an airplane, that is, fuselage, wing, horizontal tail, vertical tail, and landing gear.

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a. 1940-1948, Airplane first failure. The data represents a wide range of airplanes from liaison to bomber and the two predominant materials, wood and aluminum. Because of the type of loading used (lead shot or sand filled bags), it was not always possible to state the exact percent of ultimate load at which the component failed. Hence, the failure occurred between the last load the structure held and the next load level which it could not hold. This leads to the discontinuous box type of curve. The data shows that 25-30 percent of the airplanes had a first failure below limit load and 10-16 percent of them had a first failure below 80 percent of limit load. These failures below limit load indicate that many of the airplanes would have experienced operational problems if they had not been static tested.

b. 1950-1976, Airplane first failures. The distribution of failures is remarkably similar to that of the 1940s. However, one can draw some conclusions which may be more intuitive than actual. For example, it appears that there are fewer failures below 60 percent of ultimate, supporting the notion that more is known technically so fewer errors have been made. But, on the other end, 90 to 100 percent of ultimate load, it appears we learned too much (took too many of the conservatisms out of the analyses) and didn't quite have all of the structure needed to carry ultimate load.

c. 1940-1948 and 1950-1976, Major component first failures. Obviously the second failure of an airplane must occur at a higher percentage of ultimate load than the first failure. Hence, these curves will lie above their respective airplane first failure curves. It appears that the major component first failure curves are quite similar to the airplane first failure curves, even at the high end, supporting the removal of conservatisms trend.

As data becomes available from programs wherein the airplane is designed to durability and damage tolerance requirements, it will be interesting to see if the curves and trends change. Further, as more and more structures are made of composites, it will be equally interesting to see what happens. It appears that both of the above aspects will tend to decrease the number of static test failures, at least those associated with the classical tension, shear, torsion and bending failures. It is not apparent that the structural instability (buckling, etc.) problems have been completely solved. Nor have the secondary and flight control system structural problems been solved, (see figure 27). Note that both figures 26 and 27 are plotted to the same scale, albeit figure 26 has a broken ordinate scale and figure 27 has a broken abscissa scale. Some of these problems will probably always be with us and, just around the corner, waiting for someone to decide not to run a proof test of the first article or not to perform a static test of a major component, particularly those that are stability critical.

A.4.10.5 Static strength.

Laboratory load tests of instrumented airframe and major parts thereof, shall verify that the airframe structure static strength requirements of 3.10.5 are met. This instrumentation is required to validate and update the structural strength analyses. The applied test loads, including ultimate loads, shall reflect those loads resulting from operational and maintenance loading conditions.

VERIFICATION RATIONALE (A.4.10.5)

Verification of airframe static strength can only be accurately and safely accomplished by static tests. The analytical determination of airframe external loads, internal loads, and resulting stresses is limited by the methodologies available, by the assumptions used and, also, by the idealizations that are usually required. To date there is no proof that these analytical limitations have been minimized to the point whereby complete static testing of military aircraft can be eliminated. Better strength analysis techniques have not improved test results to a degree

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significant enough to downgrade static test requirements. The objectives of any static test program are to:

a. Ensure that the basic design is structurally adequate for the required ultimate loads.

b. Determine the degree of compliance with prescribed structural criteria.

c. Determine the amount of growth potential in the air vehicle structure (conversely--to determine potential weight-cutting areas based on precise data).

d. Alleviate and prevent future structural maintenance problems.

Extrapolating strength proof test measurements of structure critical in compressive instability is not likely to be reliable. Only by including a complete ultimate load static test program, can the full potential of the aircraft be realized.

VERIFICATION GUIDANCE (A.4.10.5)

The static test program consists of a series of laboratory tests conducted on an instrumented airframe that simulate the loads resulting from critical flight, landing, and ground handling conditions. Thermal environmental effects are simulated along with the load applications on airframe where operational environments impose significant thermal effects.

VERIFICATION LESSONS LEARNED (A.4.10.5)

See 3.10.5 Lessons Learned.

A.4.10.5.1 Development tests.

The contractor shall conduct development tests as defined herein. These tests are for the purpose of establishing design concepts, providing design information, establishing design allowables, and providing early design validation. These tests are critical in reducing and managing the design risk such that the program goes into the full scale static test with a reasonable chance of success.

VERIFICATION RATIONALE (A.4.10.5.1)

Development tests are necessary for obtaining early substantiation of newer, metallic or nonmetallic materials allowables, which will be used in the strength analyses for verifying design sizing. Development tests are also necessary for obtaining early strength validations of unique design configurations. These tests aid a manufacturer in determining if specific structural features, material systems, manufacturing techniques, etc., adequately meet the static strength, durability, and damage tolerance requirements for the airframe.

VERIFICATION GUIDANCE (A.4.10.5.1)

Examples of design development tests are tests of coupons, small elements, splices and joints, panels of basic sections, and those with cutouts or discontinuities, fittings, and operating mechanisms. These tests should be followed by tests of long lead time critical components such as wing carry-throughs, horizontal tail spindles, wing pivots, etc. The development tests must be orderly and timely in order to correct deficiencies prior to production and, particularly, to incorporate as many changes as necessary in the full scale test program.

The strength for composites are linked to the development tests. In support of these analyses it is recommended that the development testing consist of "building blocks" ranging from coupons to elements, to subcomponents, and finally components. These building block tests must include room temperature dry laminates. Also, if the effects of the environment are significant, then environmentally conditioned tests must be performed at each level in the

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building block process. The test articles are to be strain gaged adequately to obtain data on potentially critical locations and for correlation with the full scale static test, and in addition, the test program is to be formed so that environmentally induced failure modes (if any) are discovered. The design development tests are complete when the failure modes have been identified, the critical failure modes in the component tests are judged to be not significantly affected by the nonrepresentative portion of the test structure and the structural sizing is judged to be adequate to meet the design requirements. For static test components, this judgment is based on adjusting the failure loads to the B basis environmentally conditioned allowable.

VERIFICATION LESSONS LEARNED (A.4.10.5.1)

Lack of timely and comprehensive development test programs for some aircraft has caused very late discovery of significant strength and durability problems. This has led to extremely costly retrofit programs.

A.4.10.5.1.1 Design development tests.

Where data does not exist or is incomplete, these tests are to establish design concepts and to provide design information and early design validation. Design development tests shall include but not be limited to:

a. Element test (coupons/elements). These tests are typically run with sufficient sample size to determine a statistical compensated allowable.

(1) Material selection properties including structural design allowables.

(2) Environmental effects including temperature, moisture, fuel immersion, chemicals, etc.

(3) Fastener systems, fastener allowables, and bonding evaluation.

(4) Process evaluation including all corners of the allowable processing window.

b. Structural configuration development tests (subcomponents/components). These tests are typically run with a smaller sample size and as such the results are used to validate the analytical procedures and establish design allowables. Actual material properties and dimensions should be used when determining correction factors, and the lower range of test results used for design allowables compatible with the statistical requirement of 3.2.19.1.

(1) Splices and joints.

(2) Panels (basic section).

(3) Panels with cutouts.

(4) Fittings.

(5) Critical structural areas which are difficult to analyze due to complexity of design.

(6) Manufacturing methods evaluation including all acceptable variations such as gaps, pulldown, shimming, etc.

(7) Composite failure modes and strain levels.

(8) Environmental effects on composite failure modes and failure strain levels.

c. Large component development tests. These tests are to allow early verification of the static strength capability and producibility of final or near final structural designs of critical areas. The actual number and types of tests will depend upon considerations

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involving structural risk, schedule, and cost. The large component tests should be of large assemblies or full scale components such as wing carry through, horizontal tail support, wing pivots, landing gear support, complex composites, large structural castings, or any unique design features with design unknowns in:

(1) Splices and joints.

(2) Fittings

(3) Panels

(4) Stability critical end or edge fixates

(5) Out of plane effects in composites

(6) Post buckled structure

(7) Environmental effects on composite failure modes and failure strain levels

d. Design development testing approach for composites. A building block approach to design development testing is essential for composite structural concepts, because of the mechanical properties variability exhibited by composite materials, the inherent sensitivity of composite structure to out of plane loads, their multiplicity of potential failures modes, and the significant environmental effects on failure mode and allowable. Special attention to development testing is required if the composite parts ultimate strength is to be certified with a room temperature/lab air static test. Sufficient development testing must be done with an appropriately sized component to validate the failure mode and failure strain levels for the critical design cases with critical temperature and end of life moisture.

VERIFICATION RATIONALE (A.4.10.5.1.1)

VERIFICATION GUIDANCE (A.4.10.5.1.1)

VERIFICATION LESSONS LEARNED (A.4.10.5.1.1)

A.4.10.5.2 Static tests - complete airframe.

Static tests, which include tests to design ultimate load, shall be performed on the complete, full scale airframe to verify its ultimate strength capability. This requirement shall be considered complied with, if specifically approved by the acquisition activity, on the airframe or components, thereof, for which it can be shown that:

a. The airframe and its loadings are essentially the same as that of a previous airframe which was verified by full scale tests; or

b. The strength margins, particularly for stability critical structures, have been demonstrated by major component tests; or

c. The components have been designed to the factors of uncertainty of ______, as verified by strength analysis and data, and the design allowables for critical features (such as stability critical structure, complex or new design concepts, etc.) have been demonstrated by large component tests. This method does not constitute completion of an ultimate static test in meeting the requirements of 4.10.5.3, 4.10.5.4, 4.10.5.5, 4.10.7, and 4.10.8.

VERIFICATION RATIONALE (A.4.10.5.2)

Static tests up to and including ultimate loads are necessary for verifying the structural strength of the airframe. The airframe's factor of uncertainty is verified by successfully completing the

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ultimate load tests. Satisfactory demonstration of the ultimate strength capability is needed before releasing the air vehicle to operate up to 100 percent limit loads. Complete airframe, or equivalent, static tests are the only way that the strength of the structure can be demonstrated in areas of complex interactions between major components. The use of a 1.875 factor of uncertainty in blank c., above, is equivalent to maintaining a minimum margin of safety of 0.25 when a factor of uncertainty equal to 1.50 is used. This allows airplane operation to 100 percent of design limit load, while retaining the same level of safety as the conventional, 80 percent limit load flight restriction of 3.10.7, however this level of safety is not considered acceptable for a fleet of aircraft, but may be acceptable for a small number of flight test vehicles.

VERIFICATION GUIDANCE (A.4.10.5.2)

Prior to starting the static tests, structural modifications, required as a result of any failures that occur during design development tests, need to be incorporated into the test article. Ultimate load test conditions are selected for substantiating the strength envelope for each component of the airframe. The internal loads and stresses are commonly used to determine the most critical load conditions. It is recommended that the blank in 4.10.5.2.c., above, be completed by inserting a minimum value of 1.875. A larger factor of safety might be justified whenever unconventional aircraft components exist, when unusual dynamic loading might occur, or where manufacturing critical parts are being tested.

Full scale testing is an essential element of ASIP. The full scale static test is essential for the verification of the composite structure. This test is, of course, also essential for the verification of the metallic structure. This test to ultimate may be performed without environmental conditioning only if the design development tests demonstrate that a critical failure mode is not introduced by the environmental conditioning. To provide assurance that the component static tests are representative of the component tests, these articles must be extensively strain gaged. A test of the structure to failure is a program option. If the failure mode criterion cannot be met, then the static test article must be environmentally conditioned.

For metals and nonmetals, the "B" basis allowable divided by the mean strength of the coupons used for the "B" basis allowable calculation is the fraction of the strength allowed when interpreting the results of single complex component tests unless the specific mean strength of the failure location can be determined.

VERIFICATION LESSONS LEARNED (A.4.10.5.2)

During testing up to ultimate loads, tables XXIII through XXIX reflect that static tested airplanes experience substantial failure occurrence rates. Designing to a 1.875 factor of uncertainty in conjunction with a proof test was successfully applied to two prototype fighter airplanes.

A.4.10.5.2.1 Static testing of composites.

To establish the test demonstrated strength level, and account for the degradation of material properties due to combined temperature and moisture effects, in order of preference, one of the following methods shall be applied to the testing of composites:

a. Environmentally precondition the test article for the worst case combination of temperature-moisture condition and test under these conditions to 150 percent design limit load.

b. Test the composite article at room temperature with lab air to a load level in excess of ultimate to demonstrate the environmental knock down factors for temperature and moisture. The strains measured at 150 percent design limit load in the critical location of

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the composite structure must be less than the failure strains in the environmentally conditioned development tests for the same design details and loadings. Development testing must also show that there is no change in failure mode between environmental conditioned and room temperature/lab air. Development testing must also validate the statistically compensated knock down factor. It is recognized for hybrid structure (metallic and composite) that failure may occur prior to achieving the environmentally compensated load level. If the environmental knock down is greater than 10 percent, this approach requires the approval of the procuring agency.

VERIFICATION RATIONALE (A.4.10.5.2.1)

The test article configuration must be as structurally identical to the operational article as practical, in order that close simulations of operational loads and resulting stresses may be attained during the static tests.

VERIFICATION GUIDANCE (A.4.10.5.2.1)

Insert in the blank an identification of the test article such as an early FSD airframe or a Research Development Test and Evaluation (RDT&E) airframe or major components of the airframe that may be used to satisfy the static test verification requirements.

Test articles are fabricated to be structurally identical to the structure of the flight articles, except that:

a. Items such as fixed equipment non-structural fairings and useful loads and their support structures may be omitted from the test structure, provided the omission of these parts does not significantly affect the load, stress or thermal distributions and the structural characteristics of the parts of the structure to be tested, and provided the omitted parts are qualified by separate tests.

b. Substitute parts may be used, provided they produce the effects of the parts for which they are substituted and provided the structural integrity of the parts for which substitutions are made are demonstrated in a manner that is satisfactory.

c. Power plants and accessories are replaced by design-and-fabricated test fixtures that properly transmit the power plant loads to the engine mounts, vibration isolators, or both, as applicable. The means for applying the loads to these fixtures (such as loading rods through the fuselage or engine nacelle structure) are determined. All structural modifications necessary to accommodate the loading devices should be designed in such a manner so as to ensure that the structural characteristics of the modified structure will be equivalent to those of the actual structure.

d. Paint or other finishes that do not affect the structural performance may be omitted from the test structures. When the structural test includes simulation of chemical or thermal environment, the test articles include the associated environmental protection systems under the durability requirements of 3.11.

e. A number of buttock lines, water lines, fuselage stations, and wing stations are usually marked on the test structure. These should be clearly identified and should be of sufficient number to facilitate determining all desired reference points on the airframe.

f. To the extent required for adequate load simulation during test, mechanical portions of the flight control system and power actuators for the control systems are made operable. Special provisions are made for external power attachments to the actuating mechanisms to permit externally controlled operations. It is therefore permissible to omit any unnecessary portions of the normal internal power systems. Other actuators for landing gear doors,

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armament bay doors, etc., are made externally operable as required for tests. Air actuated systems may be replaced by hydraulic systems to simplify testing procedures. The external actuation capability is also recommended for tests conducted by the contractor, if test operations can be simplified or costs reduced.

g. Structural parts and mechanisms which are subject to special qualification requirements outside the scope of this specification are qualified to the extent possible prior to incorporation in the test article. For example, Class I castings must conform to MIL-C-6021.

VERIFICATION LESSONS LEARNED (A.4.10.5.2.1)

A.4.10.5.2.2 Complete airframe versus separate components.

With approval by the acquisition activity, static tests may be performed on a complete airframe or on separate, major components (such as wing, fuselage, empennage, landing gear, etc.).

VERIFICATION RATIONALE (A.4.10.5.2.2)

Testing of separate, major components may be required, since the complete airframe may be too large to fit within available test facilities. Even though total costs may be higher by performing tests on separate, major components, advantages may be gained through early, design development testing to enhance schedules.

VERIFICATION GUIDANCE (A.4.10.5.2.2)

When tests of components or separate assemblies are conducted, the test article is mounted in supporting and loading fixtures which accurately simulate the load and deflection interactions with the adjacent structure not being tested. Whenever these actual interactions cannot be attained, it is then customary to provide sufficient transitional test structure with strength and stiffness representative of the full scale airframe.

VERIFICATION LESSONS LEARNED (A.4.10.5.2.2)

4.10.5.2.3 Test loadings.
The test loads shall be applied using a system capable of providing accurate load control to all points simultaneously and shall contain emergency modes which can detect load errors and prevent excessive loads. In each test condition, parts of the structure critical for the pertinent loading shall be loaded with the best available loads.

VERIFICATION RATIONALE (A.4.10.5.2.3)

It may be necessary, initially, to use analytically derived loads to set up the test loading system.

VERIFICATION GUIDANCE (A.4.10.5.2.3)

Testing may be initiated using analytically derived loads and wind tunnel data. Loads measured in the flight and ground loads survey program are used to correct the test loads and distributions at the earliest possible time, when the measured loads are significantly different from analytical loads. The distribution of test loads customarily represent the actual, measured distribution as closely as possible.

VERIFICATION LESSONS LEARNED (A.4.10.5.2.3)

A.4.10.5.2.4 Simplification and combination of loading.

Simplifying loading conditions and combining the loading conditions shall be considered during the tests, provided the method and magnitude of resultant loadings do not induce unrepresentative, permanent deformations or failures. Loads resulting from pressurization shall

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be considered and, if critical, shall be simulated in combination with the applicable flight and ground loads during the appropriate component or full scale test.

VERIFICATION RATIONALE (A.4.10.5.2.4)

Simplification and combination of loading during tests conserve time and reduce cost.

VERIFICATION GUIDANCE (A.4.10.5.2.4)

Loading conditions may be simplified during tests by modifying the distribution of loads applied to regions of a structure that will not be subjected to critical loads during the loading condition being simulated or that are identical in construction to other regions of the structure that are subjected to critical loads during the same or another test condition. Simultaneously applying more than one loading condition to different portions of the structure is evaluated to ensure that the interaction of the separate loadings does not affect the critical design loading on any portion of the structure.

VERIFICATION LESSONS LEARNED (A.4.10.5.2.4)

A.4.10.5.3 Functional proof tests prior to first flight.

Prior to the first flight of the first flight article, proof tests shall be conducted to demonstrate the functioning of flight-critical structural systems, mechanisms and components whose correct operation is necessary for safe flight. These tests shall demonstrate that the deformation requirements of 3.2.13 have been met. The functional proof tests that will be conducted, the articles on which they will be conducted, and the load level to which the systems, mechanisms and components will be loaded are: ________________. Where these tests are not performed on every flight air vehicle, the substantiation that the planned test program is adequate to demonstrate the flight safety of all flight air vehicles is documented in ____________________.

VERIFICATION RATIONALE (A.4.10.5.3)

The purpose of these functional proof tests is to demonstrate that flight-critical structural systems, mechanisms, and components function satisfactorily when subjected to the applicable maximum operating and overshoot loads, or any lessor load.

VERIFICATION GUIDANCE (A.4.10.5.3)

The demonstration of the correct functioning of flight-critical structural systems, mechanisms, and components is required prior to their first flight use. This correct functioning is demonstrated through structural tests of the actual flight air vehicles or approved representative test articles. In all cases where the demonstration testing is not done on all flight air vehicles, the applicability of the limited testing to all flight air vehicles must be demonstrated.

One of the primary reasons for conducting these tests is to demonstrate that the deformation requirements of 3.2.13 are met so as to preclude loss of control of the air vehicle through bindings or interferences between movable components and adjacent structures or due to excessive deflections of the movable components. To ensure that these requirements are met, the tests should include the introduction of load, thermal, or other induced deformations into the critical components as well as into the adjacent structural members to which it is attached and any other structural members whose deflections may introduce binding, interference, or chaffing. Consideration should also be given to other subsystems, such as electrical or hydraulic, whose installation may cause interference when the overall airframe deforms under load.

The first blank is completed by listing the flight-critical systems, mechanisms, and components which will be tested, by defining which flight air vehicles or test articles will be used to conduct

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each test and by defining what load levels, expressed as a percentage of limit loads, to which the tests will be performed.

All structural and load carrying systems, mechanisms, and components of the air vehicle should be reviewed to determine which are flight-critical. Typical examples of flight critical systems, mechanisms, and components are: control surfaces; movable surfaces; control and movable surface drive mechanisms; control cables; rods and pulleys; control sticks and rudder pedals; and pressure control systems. In advanced air vehicles such systems as active and passive thermal control systems may also be flight-critical.

Primary structural members, such as the wings and the fuselage, are not normally included in the list of functionally flight-critical components. The requirement to test these components to demonstrate adequate strength is addressed in 4.10.5.4. It is necessary, however, to include such members when a new or unique function of the component is flight-critical. For example, an aeroelastically tailored forward-swept wing has a flight-critical stiffness function that should be demonstrated prior to flight. If a strength proof test of the wing, in which the actual stiffnesses would be measured, was not performed, then a separate functional proof test to measure the actual stiffnesses would be necessary. Also, as discussed above, it may be necessary to load primary structural members in the functional proof test to demonstrate compliance with the deformation requirements.

The normal requirement is to perform the functional proof tests on all flight air vehicles since they are intended to ensure that the article-to-article variations that occur during fabrication do not cause loss of control or loss of the vehicle. It may be possible to conduct representative tests on a single flight air vehicle, a static test article, or a large component test article and show through analyses and measurements of tolerances that the test results are applicable to the other flight air vehicles. Special attention to the proposed test methods is needed to ensure that a test of a single air vehicle can be shown to be representative of all flight air vehicles. If all flight air vehicles will not be tested, the document which substantiates the adequacy of the proposed alternative test methods is identified in the second blank.

The load level to which the functional proof test is normally performed is 100 percent of the limit loads. A value above 100 percent may be necessary where the functional test is to be representative of other flight air vehicles. A value below 100 percent is not recommended.

It is important to distinguish between the requirements for a functional proof test and a strength proof test for control surfaces, drive mechanisms, etc. The limit loads on such components may occur within the flight envelope and usually cannot be effectively restricted by establishing vehicle maneuver limitations. The functional proof test is intended to demonstrate proper functioning of these components up to and at their maximum loads, regardless of where they occur in the flight envelope. However, the functional proof tests per the requirements of this paragraph are not alone sufficient to clear these components for use up to limit loads. The strength proof test requirements of 4.10.5.4 must still be met if flight restrictions on the use of control surfaces, drive mechanisms, etc. are not to be required.

In determining the functional proof loads to be tested, the loads occurring during upsets and the recovery from upsets and the loads occurring due to the system failures of 3.2.22 should be addressed. In some cases, it may not be feasible to establish flight restrictions on such loads as is done in establishing maneuver and speed restrictions. If this is the case, then the corresponding limit loads should be used.

In air vehicles which include electronic flight control systems which regulate the position and/or load of the control surfaces or other moveable surfaces, the correct functioning of these control

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systems may need to be demonstrated during the functional proof tests if acceptable alternative tests are not performed.

VERIFICATION LESSONS LEARNED (A.4.10.5.3)

4.10.5.4 Strength and pressurization proof tests.

Strength proof tests shall be successfully performed on every airframe or parts thereof to be operated before ultimate load static tests are successfully performed or if static tests are not performed. Pressurization proof tests shall be successfully performed on every airframe prior to pressurized flight. These proof tests shall demonstrate that the deformation requirements of 3.2.13 have been met at all load levels up to the maximum loads expected to be encountered during flight for flight anywhere within the released flight envelope including the effects of recovery from upsets and the system failures of 3.2.22. These proof tests shall also validate the accuracy of the strength predictive methods through comparisons of measured critical internal loads, strains, stresses, temperatures, and deflections with predicted values. Re-proof tests shall be conducted when flight test data indicates that actual loads or load distributions are more severe than those used in the previous proof tests. In cases where these tests are not fully representative of the actual flight environment, where the scope of the planned proof tests is not complete or where all air vehicles normally tested will not be tested, the substantiation of the adequacy of the planned proof tests is documented in ____________________.

a. Strength proof test load levels shall be equal to _______________ percent of limit mechanical loads or the maximum mechanical loads to be encountered during flight, each multiplied by a factor of ____, whichever is less to account for overshoot, and _______________ percent of limit thermal loads or the maximum thermal loads to be encountered in flight, each multiplied by a factor of ____, whichever is less to account for overshoot. The proof load distributions shall be equal to or more severe than the predicted load distributions.

b. Prior to the first flight with pressurized compartments, each pressurized compartment of each pressurized flight air vehicle shall be pressure proof tested to _______________ percent of the maximum pressure limit loads of 3.4.1.12. Subsequent to the successful completion of ultimate pressurization tests on the static test article, each air vehicle shall be pressure proof tested to the maximum operating pressure differential attainable with normal pressure control system operation multiplied by a factor of _______________. Where necessary to demonstrate combined external load and internal pressurization strength, the pressure proof tests shall be combined with the strength proof tests of subparagraph a. above.

VERIFICATION RATIONALE (A.4.10.5.4)

The purpose of these proof tests is to demonstrate the capability of each airframe that will be released to fly beyond the initial restricted flight envelope to withstand the maximum mechanical and thermal loads expected to be encountered in flight and the maximum pressurization loads without failure or detrimental structural deformation.

VERIFICATION GUIDANCE (A.4.10.5.4)

Air vehicles are normally only released to fly beyond the interim strength flight release limits of 3.10.7 after the successful completion of the ultimate load static tests. In cases where such ultimate load static tests will not be performed or where these tests will not be performed until after the air vehicle has flown, it is necessary to establish an approach for permitting air

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vehicles to fly to the full loads envelope, per 3.10.7 and 4.10.7, so that flight testing of the air vehicle can be accomplished.

The normally accepted approach is to accomplish strength proof load static tests on each air vehicle that will be released for flight above the initial strength flight release limits. Through this testing, the quality of each airframe is demonstrated to be sufficient to resist the maximum loads expected to be encountered during flight within the expanded flight envelope, including the loads encountered during the system failures of 3.2.22, without structural failure or detrimental structural deformation. This demonstration of quality is achieved through the application of loads equal to or greater than the maximum loads expected to be encountered in the expanded flight envelope. These loads are applied to all major structural components using representative load distributions with representative environmental conditions. An unrestricted strength flight envelope can only be achieved through the successful completion of strength proof tests for all designing limit loads on all primary structure and flight-critical secondary structure.

The value inserted into the first blank in subparagraph a is normally equal to 115 percent. Strength proof tests are normally accomplished to a load level above 100 percent of the maximum loads expected to be encountered during flight to provide a demonstrated margin for stability critical structure, to account for inaccuracies in the proof test, and to account for expected variations in the accuracy of the predictive methods. A value greater than 115 percent should be used where uncertainties in predictive methods, load measurement methods, or static test methods are greater than normal. A value less than 115 percent is not recommended.

The value inserted into the second blank in subparagraph a should be greater than 100 percent to provide a strength margin for uncertainties in thermal load prediction and measurement methods and thermal test methods. If thermal loads are not significant for the design of the airframe or if thermal loads will not be included in the strength proof testing, insert N/A in this blank.

The value inserted in the first blank in subparagraph b is typically 100. This value should be increased in cases where the maximum pressure differentials are difficult to control especially where the potential for rapid internal pressure change exists. The value inserted in the second blank is typically 1.00. Again, this value should be increased where additional uncertainty exists in the ability to control the maximum pressure differential levels.

Special attention should be given to the determination of the strength proof test requirements for control systems: control surfaces, drive mechanisms, control sticks, cables, rods, pulleys, etc. In many cases, the maximum loads on these components do not occur at the edges of the design flight maneuver envelope. In such cases, meeting the requirements of 3.10.7 by establishing flight restrictions to limit these component loads may be difficult to achieve without unreasonably restricting the air vehicle. Such restrictions may also be difficult to implement when limits on control system loads during the recovery from upsets or following the system failures of 3.2.22 are to be determined. Strength proof testing of the control systems may be desirable to prevent having to unreasonably restrict the use of these systems.

Similar special attention should be given to the determination of the strength proof test requirements for structural components which are significantly affected by thermal loads. If it is impractical to develop interim strength flight limits per 3.10.7, due to complexities of the actual combinations of flight conditions, length of exposure, use of influencing subsystems, etc. which determine the actual thermal loads, conducting a thermal strength proof test would be necessary prior to flights where thermal loads are significant. However, such thermal tests, when combined with mechanical loads or where thermal load distributions are widely varying,

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may be difficult to implement on actual flight air vehicles. It may be easier to conduct ultimate thermal static tests on large components instead of proof tests on flight air vehicles.

VERIFICATION LESSONS LEARNED (A.4.10.5.4)

Proof pressurization failures in open areas can cause extensive structural damage and injury to personnel nearby.

A.4.10.5.5 Post proof test inspections and analyses.

Post proof test inspections, including nondestructive inspection (NDI), shall be conducted to determine if detrimental deformation has occurred in any structural part that would prohibit its usage on the airframe in compliance with the requirements of 3.2.14. Extensive examination of instrumentation data shall be accomplished to determine whether extrapolated, ultimate internal stresses are above predicted values to the extent that airframe structural flight restrictions or modifications are required.

VERIFICATION RATIONALE (A.4.10.5.5)

Results of the proof tested article must necessarily be inspected and analyzed to ensure safe operational usage of the airframe. A visual examination may not detect test induced damages, while extensive examinations of the airframe and instrumentation data may indicate the necessity of incorporating structural modifications or applying flight restrictions.

VERIFICATION GUIDANCE (A.4.10.5.5)

Stresses, reduced from instrumentation data recordings, and deflection measurements are correlated with applied test load values. Examinations of the reduced data and tested structure are made to determine if detrimental deformations have occurred. Proof test stresses are extrapolated to ultimate levels and compared with predicted stress analyses values. Structural modifications may be required for reproof testing of larger, flight measured loads.

VERIFICATION LESSONS LEARNED (A.4.10.5.5)

A.4.10.5.6 Failing load tests. (___)

When ultimate load tests are completed, failing load tests shall be conducted to fail the test airframe by increasing the test loads of the most severe test loading condition.

VERIFICATION RATIONALE (A.4.10.5.6)

Failing load tests may reflect unneeded overstrength; however, these destruction tests do determine the actual strength of the airframe for substantiating special capabilities such as growth potential or emergency operations. Failure load tests demonstrate the weakest link in the structure, for which inspections or special considerations may be required during service. Sufficient overstrength may be demonstrated overall, or by beefing up the weak points such that growth for increased range or payload may be possible.

VERIFICATION GUIDANCE (A.4.10.5.6)

If the airframe is to be tested to destruction, this paragraph is applicable. The failing load tests are not conducted until completion of the flight loads survey, so that the static test article will remain intact for conducting of any additional tests necessary. More than one failing load test may be required to attain maximum strength data. In particular, empennage failing load tests would probably be conducted separately. The major failing load condition should be the one that is most critical, overall, for the wings and fuselage. A careful post failure inspection and analysis should be utilized to determine the initial failure sites and failure modes. Failing load

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tests are normally specified in the contract unless other uses of the article are specified in the contract.

VERIFICATION LESSONS LEARNED (A.4.10.5.6)

There has, almost invariably, never been an Air Force aircraft which has not had some growth requirements imposed or desired, regardless of any words to the contrary within the initial contract. Demonstrated static overstrength has often led to satisfying increased performance demands without expensive redesign and retrofit programs. Significant overstrength, however, is not necessarily an indicator of satisfactory durability design and caution must be exercised in this respect.

A.3.10.6 Dynamic strength.

Sufficient static strength and energy absorption capability shall be provided in the airframe to react all dynamic design landing conditions and reserve energy requirements. For land-based aircraft, the maximum sink speed is _________ and the reserve energy condition is ____________. For ship-based aircraft, the design requirements are ____________.

REQUIREMENT RATIONALE (A.3.10.6)

Adequate airframe strength and energy absorption must be provided to meet the operational requirements and provide safety of flight. The results of these analyses and tests are required to conduct verification flight tests and carrier suitability testing.

REQUIREMENT GUIDANCE (A.3.10.6)

The structure and aircraft systems shall have sufficient strength and energy absorption capability so that it can carry limit and design loads without detrimental deformations which would interfere with continued operation. The structure must be able to react ultimate loads without rupture or collapsing failure.

REQUIREMENT LESSONS LEARNED (A.3.10.6)

A.4.10.6 Dynamic strength.

Prior to release for flight verification testing, component or total airframe laboratory testing shall be conducted to demonstrate energy absorption compliance and to validate design loads analysis. For land-based aircraft with maximum limit sink rates less than or equal to 10 fps, system functions may be demonstrated by component landing gear jig drops which demonstrate both design conditions and the required reserve energy conditions. For shipboard aircraft, drop tests of the complete airframe shall be conducted.

VERIFICATION RATIONALE (A.4.10.6)

This requirement establishes certification of landing gear load stroke characteristics during dynamic events and validates the energy absorption requirements. In addition, for shipboard aircraft this requirement also provides certification of the shock environment of installed mass items (avionics equipment, hydraulic systems, engines, stores, etc. as well as providing confidence that no interference of adjacent structure/components occur, i.e. deflection.

VERIFICATION GUIDANCE (A.4.10.6)

Navy drop tests. Tests shall be performed on a structurally complete strength test structure and shall include wheel spin-up sufficient to simulate critical effects of wheel contact velocities within the range of contact velocities included in land-based and carrier-based landing design requirements. The wheel radii employed in the determination of wheel speeds shall be the

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static rolling radii of the tires. For carrier-based airplanes, the landing design gross weight shall be the carrier-landing design gross weight. For noncarrier-based airplanes, the landing design gross weight shall be landplane landing design gross weight. Maximum tire pressures, strut fluid volume, and strut air pressure employed in drop tests shall exceed neither those practicable for service use nor those actually recommended in the erection and maintenance instructions as appropriate for land-based operation, carrier operation, or simulated carrier landings. Wing lift forces shall be applied. The cockpit shall be instrumented to measure accelerations which would be experienced by the crew to assure that excessive accelerations are not experienced. Coefficients of friction developed in drop tests shall be representative of those occurring in landings on paved runways and carrier decks. Drop tests to maximum design sinking speeds shall be performed at the gross weights and weight distributions specified and also with alternate combinations of internal and external loads for which provisions are required in flight articles, that may be structurally critical by virtue of transient effects or otherwise. For these specified and alternate combinations of loads, the mass, center of gravity position, and method of support of internal and external equipment and stores of appreciable mass, as well as the dynamic motions of fuel or other fluid pressure effects that are structurally significant, shall be accurately simulated. Residual stresses shall be measured at critical landing gear locations both before and after testing to design sink speeds.

Landing gear servicing tests. Tire inflation pressures, strut fluid volume, strut air pressure, and extreme values of other factors that can be varied to thereby influence shock absorption and rebound characteristics shall be such as to attain the most favorable and alternately the least favorable shock absorption and rebound characteristics consistent with specified design requirements. Each of the tests shall be performed twice in the symmetrical attitudes which have been shown by prior drop tests to be critical for the main and, alternately, critical for the nose gear. During these tests, it shall be demonstrated, in successive drops not more than 5 minutes apart, that the shock strut fully recovers its shock absorption abilities. Upon completion of the symmetrical drops, tires shall be deflated, fluid shall be removed, and other changes and adjustments possible in normal operations shall be made. The landing gear shall then be readjusted and serviced by normal, planned fleet maintenance procedures. It shall be demonstrated that each dry deflated strut can be serviced and be ready for full shock absorption in not more than 30 minutes. These tests may be done during landing gear jig drop tests. Data shall be submitted.

VERIFICATION LESSONS LEARNED (A.4.10.6)

A.3.10.7 Initial and interim strength flight releases.

Initial and, as needed, interim strength flight restrictions shall be established to maintain safe flight conditions until all structural validation testing has been successfully completed. The loads resulting from overshoots, upsets, and the recovery from overshoots and upsets, and the loads during and following the system failures of 3.2.22 shall be included in the establishment of the flight restrictions.

a. For the initial strength flight release, flight restrictions shall be defined to restrict the air vehicles from experiencing loads greater than _______________ percent of limit loads. These loads shall be determined as a function of applicable structural validation testing with a factor of ____ or strength proof testing with a factor of ____.

b. Prior to the completion of all structural validation testing, interim strength flight releases shall be defined to permit flight up to the lesser of the strength envelope cleared through the strength proof testing of 4.10.5.4 or strength analyses with a risk mitigation factor of ___ to include accommodation of design complexity and available instrumentation values.

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REQUIREMENT RATIONALE (A.3.10.7)

This requirement provides the approach for establishing the initial and interim strength flight restrictions for flight test and production air vehicles.

REQUIREMENT GUIDANCE (A.3.10.7)

The value inserted into the blank is typically 80 when the expected accuracy of the loads predictions, structural analysis methods and fabrication methods is high. A lesser value should be specified where an unusual design, unusual usage, new materials, etc., lower the expected accuracy of the predictive methods or quality of fabrication, or where the ability to fly within defined restrictions is more difficult than normal.

The discussions involving limit loads include both external mechanical loads as well as externally or internally generated thermal loads.

REQUIREMENT LESSONS LEARNED (A.3.10.7)

A.4.10.7 Initial and interim strength flight releases:

a. Prior to the initial flight release, the airframe shall be satisfactorily strength analyzed for reacting all predicted limit and ultimate loads and this analysis shall be approved by the procuring activity. Also, prior to the initial flight release, the functional proof test requirements of 4.10.5.3 and 4.10.5.4 shall be successfully met if the ultimate static strength tests have not been performed. Prior to first pressurized flight of all air vehicles, the pressurization proof test requirements of 4.10.5.4 shall be successfully met.

b. Prior to flight beyond the initial strength flight release, the accuracy of the loads predictive methods shall be validated by using an instrumented and calibrated flight test air vehicle to measure actual loads and load distributions during flight within the initial strength flight release envelope. Also, prior to flight beyond the initial strength flight release, the strength proof test requirements 4.10.5.4 shall be successfully met if the ultimate static strength tests have not been performed. Extrapolations of the measured data beyond the initial flight limits shall be used to establish the expected conservatism of the predictive methods for flight up to limit loads. This procedure of loads measurement and data extrapolation shall be used to validate the conservatism of the strength analysis and strength proof tests for each incremental increase in the strength flight release envelope up to limit loads or the strength envelope cleared through the strength proof testing of 4.10.5.4, whichever is less.

VERIFICATION RATIONALE (A.4.10.7)

This requirement establishes the verifications of adequate structural strength required to approve the initial and interim flight releases.

VERIFICATION GUIDANCE (A.4.10.7)

The completed reports on the analytical determination of external loads, internal loads, and strength analyses are made available to the acquisition activity for review sufficiently in advance of the initial flight date.

VERIFICATION LESSONS LEARNED (A.4.10.7)

A.3.10.8 Final strength flight release.

Prior to final strength flight release for operation up to 100 percent of limit strength for either production air vehicles or flight test air vehicles not proof tested per 4.10.5.4, the airframe shall

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have exhibited ultimate load static test strength for ultimate loads, environmentally compensated as applicable, which reflect verified external limit loads and validated and updated structural analyses.

REQUIREMENT RATIONALE (A.3.10.8)

This requirement provides the approach for releasing the air vehicles for flight to the demonstrated limit load strength of the airframe.

REQUIREMENT GUIDANCE (A.3.10.8)

If not already released per the requirements of 3.10.7 and 4.10.5.4, the structural flight test air vehicle is released to proceed with flight testing from typically 80 percent up to 100 percent of limit load levels following the successful completion of ultimate load static tests. This flight testing is permitted to proceed, incrementally, on a flight-by-flight basis for each loading condition that has been successfully static tested. Applicable redesign, analysis, and additional static testing are accomplished when actual measured loads are in excess of analytical loads. After successful completion of the 100 percent structural flight test program, the service inventory aircraft are customarily granted flight release to operate up to the 100 percent load level.

Final certification of the strength envelope to 100 percent limit load levels, for both flight test and service inventory aircraft, is contingent upon successful completion of appropriate flight testing and ultimate load static tests. The latter includes extensive examination of static test article instrumentation to ensure that test measured values are within, or well correlated to, predicted values as adjusted by verified external loads (similar to the comparisons of 4.10.5.4 and 4.10.5.5). Structural analyses shall be validated and updated for all testing such that the predictive methods ensure adequate strength levels and understanding of the structural behavior.

Final certification of the strength envelope to 100 percent limit load levels for both flight test and service inventory aircraft is contingent upon successful completion of appropriate flight testing and ultimate load static tests. The latter includes extensive examination of static test article instrumentation to ensure that test measured values are within, or well correlated to, predicted values as adjusted by verified external loads (similar to the comparisons of 4.10.5.4 and 4.10.5.5). Structural analyses shall be validated and updated for all testing such that the predictive methods ensure adequate strength levels and understanding of the structural behavior.

REQUIREMENT LESSONS LEARNED (A.3.10.8)

The overall experience with structural flight tests within the Air Force has been good. They have substantiated that state-of-the-art loads prediction is fairly good, although load errors continue to be discovered. Of particular note are the analytical load errors revealed by flight loads surveys conducted on certain cargo aircraft during the mid-1950s and mid-1960s. However, most discrepancies observed were at the extremes of the flight envelope.

Past experience has shown that structural flight test articles have been lost and considerable program delays have resulted. During the 1950s a fighter aircraft, a bomber aircraft, and a fighter-bomber aircraft crashed before completing their flight test programs.

A.4.10.8 Final strength flight release.

For final strength flight release of the flight test article and service inventory air vehicles, the requirements of 3.10.8 shall be complied with by tests.

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VERIFICATION RATIONALE (A.4.10.8)

Early, initial static tests utilize analytically derived loads that are of limited accuracy, and which must be verified by a flight loads survey. Therefore, flight measured loads to encompass the 100 percent limit load level must be determined early so that the results can be accounted for in final static testing. For example, if the flight loads survey reveals that actual measured loads are in excess of the analytical loads, redesign with supporting analysis and additional static testing are often necessary, since the alternative of flight restrictions is not only undesirable but frequently intolerable.

VERIFICATION GUIDANCE (A.4.10.8)

The structural flight test aircraft, only, is first released for testing up to 100 percent limit load level after satisfactory completion of the 80 percent structural flight test program and ultimate load static tests. The final strength flight release of the flight test article normally requires acquisition activity approval, following receipt of satisfactory, 80 percent phase, flight test results and satisfactory ultimate load static test results.

Service inventory aircraft are released with operating limitations up to the 100 percent limit load level after satisfactorily completing the flight loads survey with the flight test aircraft. Acquisition activity approval of the final strength flight release of service inventory aircraft is usually contingent upon receipt of satisfactory, 100 percent phase, flight test results, final static test results, and the strength summary and operating restrictions reports.

Final certification of the strength envelope to 100 percent limit load levels for both flight test and service inventory aircraft is contingent upon successful completion of appropriate flight testing and ultimate load static tests. The latter includes extensive examination of static test article instrumentation to ensure that test measured values are within, or well correlated to, predicted values as adjusted by verified external loads (similar to the comparisons of 4.10.5.4 and 4.10.5.5). Structural analyses shall be validated and updated for all testing such that the predictive methods ensure adequate strength levels and understanding of the structural behavior.

VERIFICATION LESSONS LEARNED (A.4.10.8)

A.3.10.9 Modifications.

Modifications to an existing air vehicle affecting the external or internal loads on the structure, as well as new or revised equipment installations, shall have adequate structural capability for the intended usage. This requirement also applies to unmodified structures whose loads have been increased because of the modification.

REQUIREMENT RATIONALE (A.3.10.9)

Airframe modifications must necessarily incorporate sufficient structural capability to preclude the levying of excessive restrictions on air vehicle operations. The weight penalty induced by maintaining the 0.25 margin of safety limitation is quite small for the advantages gained in structural integrity.

REQUIREMENT GUIDANCE (3.10.9)

Modified primary structure and new or retrofitted equipment installations are strength designed with structural configurations to accommodate all applicable external loads and environmental conditions. Modified structure adjacent to cut, primary members (fuselage frames, longerons, wing spars, ribs, etc.) are designed to accommodate the change in load paths by using adequate material sizing techniques. Exterior surface additions and internal equipment

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installations are strength designed to accommodate applicable aerodynamic, pressurization, and inertia loads, including the effects of emergency landing crash load factors.

When strength proof tests of each modified air vehicle are not performed, it is recommended that analytical margins of safety not less than 0.25 be maintained, in order to provide an equivalent factor of uncertainty capability equal to 1.875. The modified airframe may then have the strength capability to be released to 100 percent limit load levels, based on the 80 percent, analytical strength capability. Each structural modification is normally classified as being major or minor as described by AFSCR 80-33, which covers Class II Modifications.

Unmodified structure which has been static tested to ultimate without failure may be qualified by analysis if the internal loads distribution or magnitude approximate the demonstrated static strength.

REQUIREMENT LESSONS LEARNED (A.3.10.9)

A.4.10.9 Modifications.

To verify that the airframe with modifications has adequate structural capability for the planned usage, the analyses and tests of 4.10.5, 4.10.6, 4.10.7, and 4.10.8 shall be performed.

VERIFICATION RATIONALE (A.4.10.9)

Applicable analyses and tests are necessary for verifying safety in the modified air vehicle's operations. Some airframes may be purposely modified for limited operational capability but if previously qualified airframes are to maintain comparable strength when the modification is completed, analyses and tests are necessary to verify that the original strength has not been compromised.

VERIFICATION GUIDANCE (A.4.10.9)

Verifying the modified airframe's structural integrity is customarily accomplished by performing strength analyses or revisions to previous analyses to support installation drawings; performing proof pressurization tests on pressurized compartments, when the pressure vessel has been penetrated as a result of the modification; and performing limit load, strength demonstration proof tests on significantly modified, primary structures.

VERIFICATION LESSONS LEARNED (4.10.9)

A.3.10.10 Major repairs, rework, refurbishment, and remanufacture.

The airframe of an existing air vehicle shall have adequate structural integrity and capability for the intended usage following major repairs, extensive reworks, extensive refurbishment, or remanufacture.

REQUIREMENT RATIONALE (A.3.10.10)

REQUIREMENT GUIDANCE (A.3.10.10)

REQUIREMENT LESSONS LEARNED (A.3.10.10)

A.4.10.10 Major repairs, reworks, refurbishment, remanufacture.

The major repairs, extensive reworks, extensive refurbishment, or remanufacture of an existing air vehicle shall be documented and the airframe verified by analysis, inspections, and tests. The contractor shall review, update, and reestablish the technical database on each airframe as required to verify the airframe structural integrity and to support the intended usage and

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capability. Testing is required to reestablish the technical database as analysis alone is insufficient to reestablish this technical database. Proof testing of each airframe may be the option of choice.

VERIFICATION RATIONALE (A.4.10.10)

VERIFICATION GUIDANCE (A.4.10.10)

VERIFICATION LESSONS LEARNED (A.4.10.10)

A.3.11 Durability.

The durability capability of the airframe shall be adequate to resist fatigue cracking, corrosion, thermal degradation, delamination and wear during operation and maintenance such that the operational and maintenance capability of the airframe is not degraded and the service life, usage and other provisions of 3.2.14 are not adversely affected. These requirements apply to metallic and nonmetallic structures, including composites, with appropriate distinctions and variations as indicated. Durability material properties shall be consistent and congruent with those properties of the same material, in the same component, used by the other structures disciplines. See 3.2.19.1.

REQUIREMENT RATIONALE (A.3.11)

When subjected to design service loads and environment an airframe must have adequate durability throughout its service life to preclude adverse safety, economic, operational, maintenance, repair, or modification cost impacts.

REQUIREMENT GUIDANCE (A.3.11)

The requirements of this paragraph and subsequent subparagraphs apply to all primary and secondary structures and to all structural material systems except as noted. The contractor needs to perform the analytical and test work necessary to demonstrate compliance with the durability requirements herein, in accordance with the life and usage provisions of 3.2.14.6. The objective is to demonstrate airframe resistance to cracking or other structural/material degradation which results in excessive, untimely, or costly actions in service (e.g. maintenance, inspections, repairs, modifications, etc.), in functional problems (e.g. fuel leakage, loss of control effectiveness, loss of cabin pressure, mechanical interference, etc.), or in adverse impacts to operations. Full realization of the objective results in a structure which requires no specific actions (e.g. inspections, modifications, etc.), as demonstrated by design and development, to achieve its full service life, as defined by 3.2.14.6, and thereby supports/optimizes projected airframe force inventory levels at least cost and impact to operations/readiness. Finalize the aircraft durability requirements only after careful consideration of:

a. Unique performance capabilities the air vehicle may have which differ from past air vehicles, and which in part, may nullify the existing data base

b. Potential changes in usage (for example, mission, tactics, or mission mix)

c. Potential service life extensions

d. Projected weight to at least Initial Operating Capability (IOC) based on historical data regarding weight growth during development

e. Any other change which may impact the scenario in which the air vehicle may operate

f. Combined impact of natural environmental exposure and service usage on the residual strength capabilities of the structural material. In cases where structural material systems

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are utilized which do not exhibit a classical metallic structure deterioration mechanism, i.e., fatigue crack initiation and propagation, the concept of durability life still applies. The relevant factors which could cause the deterioration of a particular structural material system must be used to define the point at which the onset or level of deterioration is unacceptable.

REQUIREMENT LESSONS LEARNED (A.3.11)

The durability and corrosion resistance of the structure is the final measure of success in service. Durability must be designed into the structure to maximize the life of the airframe and ensure its safe and economical operation. When adequate durability is not attained, adverse cost, operational and safety impacts may result. For example, a very large transport and a ground attack aircraft lacked sufficient durability margin which necessitated complete redesigns of the wing structure of the aircraft.

For background on composites, see Composite Structures/Materials Certification Background under Requirement Lessons Learned for 3.2.19.

A.4.11 Durability.

The durability requirements of 3.11 shall be detailed and included in the detailed structural criteria of 3.1.

VERIFICATION RATIONALE (A.4.11)

A comprehensive analyses and test effort, and documentation thereof, is necessary to verify demonstration compliance with durability requirements.

VERIFICATION GUIDANCE (A.4.11)

The specific tasks required to verify that the requirements of 3.11 are satisfied are contained in the individual sections that follow.

VERIFICATION LESSONS LEARNED (A.4.11)

In addition to basic airframe components, there are two major durability problem areas which should receive special consideration in the development of the detailed structural criteria for durability besides the specific stated requirements. These areas concern accessibility and system interfaces. A large percentage of the complaints from field service personnel revolve around accessibility problems associated with correcting wear and corrosion durability problems. The goal of providing maximum accessibility to all structural components and systems should be emphasized. Problems with system and structural interfaces such as fuel or hydraulic lines and brackets have resulted primarily from a lack of attention during development. It should be emphasized in the detailed structural criteria that these interfaces should be considered a part of, not added onto, the structure.

The impact of increases in the aircraft's Basic Flight Design Gross Weight (BFDGW) on the ability of the airframe to achieve the durability requirements should be considered when proposed aircraft modifications increase the BFDGW. The increased BFDGW resulting from changes such as design improvements, new avionics, and new engines may significantly decrease airframe durability unless structural modifications are incorporated. Durability analyses should be updated to reflect BFDGW changes so that areas requiring modification can be identified and the required changes incorporated and evaluated.

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A.3.11.1 Fatigue cracking/delamination damage.

For one lifetime when the airframe is subjected to the environment and service usage specified in 3.2.14 except where it is desired to meet the special life provisions of 3.11.5, the airframe shall be free of cracking, delaminations, disbonds, deformations, or defects which:

a. require repair, replacement, inspection to maintain structural integrity or undue inspection burden for ship based aircraft.

b. cause interference with the mechanical operation of the aircraft.

c. affect the aircraft aerodynamic characteristics.

d. cause functional impairment.

e. result in sustained growth of cracks/delaminations resulting from steady-state level flight or ground handling conditions.

f. result in water intrusion.

g. result in visible damage from a single _____ ft-lb impact.

REQUIREMENT RATIONALE (A.3.11.1)

When subjected to design service loads and environment, an airframe must resist fatigue cracking/delamination damage and other structural anomalies (e.g. disbonds, deformations, defects, etc.) throughout its service life to preclude adverse safety, economic, operational , maintenance cost impacts.

REQUIREMENT GUIDANCE (A.3.11.1)

See 3.11 Requirement Guidance.

To satisfy durability requirements and account for data scatter, structural anomalies should not occur within two lifetimes of usage and environments specified in section 3.2.14. While the full scale durability test results are the primary indicators of compliance, the durability analysis supports key elements in the development of durable structure by establishing stress levels, aiding in definition of structural details and reducing risk relative to testing.

Composite structures, as well as metal structures, must be designed to minimize the economic burden of inspecting or repairing damage from low energy impacts such as tool drops, etc. Specifically for organic matrix composites, service induced damage should be considered (e.g., low velocity impact damage, maintenance and handling damage, etc.) and the potential effect on repair, maintenance, and function must be developed. It should be demonstrated that damage not readily visible on the surface will not result in subsequent degradation of the part, impair function, or require maintenance actions. Visible damage is defined as damage that is visible to the unaided eye from a distance of 5 feet (dent depths of 0.10 inch). The intent is to ensure that costly maintenance will not be incurred due to service exposure. The structure and potential service and maintenance environment should be reviewed to develop typical damage sources. To accomplish this goal, the structure is to be divided into two types of regions. The first type is one where there is a relatively high likelihood of damage from maintenance or other sources. The second type of region is one where there is a relatively low probability of the structure being damaged in service. The specific requirements for these two areas are given in table VII. There are two other threats to the structure that may cause an economic burden. These threats are hail damage to the aircraft when parked and runway debris damage to the aircraft from ground operations. The hailstone size for which the structure must be hardened was chosen such that this size or smaller were representative of 90 percent of the hailstorms. The runway debris size was also chosen to include most of the potentially damaging objects

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found in ground operations. The velocity of these objects is dependent on the weapon system. The details of the hail and runway debris requirements are shown in table VIII.

The structure should be designed such that the above sources will not incur damage of sufficient magnitude to require inspection or repair throughout two times of design service life usage at the critical environmental condition. The loading spectrum and environmental conditioning for the testing associated with the table VII and table VIII requirements will be the same as that described for the durability tests.

REQUIREMENT LESSONS LEARNED (A.3.11.1)

A.4.11.1 Fatigue cracking/delamination damage.

The durability analyses and tests shall be of sufficient scope to demonstrate that the airframe structure meets the requirements of 3.11.

VERIFICATION RATIONALE (A.4.11.1)

A comprehensive test and analysis effort is required to develop a durable structure.

VERIFICATION GUIDANCE (A.4.11.1)

The specific tasks required to demonstrate compliance with the requirements of 3.11.1 are defined in the following subparagraphs. The verification of the economic life of the airframe requires an extensive evaluation and interpretation of the results of development analyses and tests, full-scale tests, and post test analyses. Because of analytical limitations and testing complexity, an individual analysis or test requirement cannot be formulated such that supporting information from the other development requirements is not needed. Further, the economic life of the airframe cannot be determined without a full scale durability test.

VERIFICATION LESSONS LEARNED (A.4.11.1)

As indicated in the guidance above, the verification of the economic life of the structure cannot be done by analysis or test alone. It is important that a well balanced effort be conducted addressing analysis, development testing, and particularly the full-scale testing.

A.4.11.1.1 Analyses.

The analytical requirements of 3.11.1 can be met by either one of the following methods but the analysis method or methods selected shall be compatible with the user's life management concept. Beneficial effects of life enhancement processes must be approved by the procuring activity. The general service life requirement is specified in 3.2.14 whereas special life requirement is specified in 3.11.5.

a. Fatigue analysis with a scatter factor of _______ applied shall support two design service lives of testing without crack initiation. Specific scatter factors shall be applied such that crack initiation shall not occur in ______ analytical lives for ship-based and land-based aircraft, and corresponding back-up structure, high strength structure, and other special structures.

b. Crack growth analysis from a typical manufacturing initial quality flaw shall not grow to functional impairment in two times design service life.

While these analytical methods are considered equivalent to determine the design product configuration, sizing, and robustness, special situations can occur for certain material/spectrum combinations where the fatigue, crack growth, and fracture toughness characteristics are not

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balanced. In these special situations, the analytical method and/or flaw sizes must be approved by the procuring agency.

VERIFICATION RATIONALE (A.4.11.1.1)

A verified durability analysis methodology is required to establish design stress levels, aid in definition of structural details and reduce risk for the full scale test phase, interpret test results, and provide a means to assess the impact of usage variations on the life of the structure.

VERIFICATION GUIDANCE (A.4.11.1.1)

A durability analysis methodology must be established to show compliance with the requirements of 3.11.1 and 3.14.6. The analysis methods must correlate with the development and full-scale test results and be directly compatible with the applicable user life management concept. The recommended approach is based upon combined fracture mechanics and fatigue crack initiation analyses; although one analysis will be considered primary and the other secondary depending upon the nature of the respective user tracking program (i.e. crack growth or safe-life method). Both types of analyses should be employed from a design stress screening standpoint and both analyses should predict that no specific actions (e.g. inspections, modifications, etc.) are required in two times design service life durability testing. In situations where the two analyses produce inconsistent results, a mutually agreed upon approach should be selected on a case by case basis.

The durability fracture mechanics based analysis should demonstrate that an assumed initial flaw in typical quality structure would not propagate to a size which would cause functional impairment in two lifetimes of the design analysis spectrum (3.2.14.6), and that, additionally, it is unlikely that, by means of crack initiation analysis, fatigue cracks will initiate in the same period of time.

The durability crack initiation based analysis should support the premise that no fatigue cracks will initiate in two times design service life test and that, additionally, but secondarily, it is unlikely that, by means of durability fracture mechanics analysis, an assumed initial flaw will propagate to a size which will cause functional impairment in two lifetimes of the design analysis spectrum (3.2.14.6). Based upon past experience, factors between 2.67 (crack initiation coupon data) and 4.00 (whole life coupon data) have been applied in the fatigue analysis to support no crack initiation in two test lifetimes. Due to the difference in analysis methods, the contractor should prove, demonstrate, and provide supporting data bases to verify that their methodologies can accurately predict structural component lives.

For landing gear, landing gear back-up structure, high strength structure, and special structure, the specified analytical factor on design life shall be between 2.0 and 4.0 as a function of spectrum severity, consequence of failure, material damage tolerance characteristics, weight, cost trades, etc, subject to the approval of the procuring activity. For example, the single point failure mode and catastrophic consequences of failure during the catapult evolution of ship-based operations mandates additional safety margin in both the nose landing gear and the corresponding airframe back-up structures. To ensure structural integrity, an analytical factor of 4 and a spectrum including catapults, landing, and related ground events has been applied. Carrier based aircraft main landing gear and back-up structure, however, have previously implemented a two lifetime requirement as function of the spectrum severity and less catastrophic implications of failure. Land-based aircraft landing gear structure have previously implemented a four lifetime requirement as a result of spectrum severity and material damage tolerance considerations.

The following definitions apply:

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a. Assumed initial flaw size: For initial design, an .01 inch radius corner flaw at stress risers and an .01 inch deep by .03 inch long surface flaw at other locations are to be assumed. Alternate flaw shapes and sizes can be utilized where appropriately based on an equivalent stress intensity or an equivalent initial flaw size approach. These assumptions can be verified or modified or both based on the testing of 4.11.1.2.

b. The beneficial effects of interference fasteners, cold expanded holes, shot peening, or other specific joint design and assembly procedures may be used in achieving the durability analysis requirements. For durability fracture mechanics analysis, the limits of the beneficial effects to be used in design should be no greater than the benefit derived by assuming a .005 inch radius corner flaw at one side of an as manufactured, non-expanded hole containing a neat fit fastener in a non-clamped-up joint. For durability fatigue crack initiation analysis, the design stress levels must be compatible with one lifetime without, and three lifetimes with, beneficial effects.

c. Crack size that would cause functional impairment:

(1) In pressurized areas of area containing fuel, this crack size is the size which would provide a direct flow path for the fuel to escape or prevent the maintenance of the required pressure.

(2) For stiffness structure or structure that is subjected to compressive loading, this crack size would be that which could produce local instabilities or cause undesirable structural deflections.

(3) In other areas that are readily accessible, this crack size would be the edge distance (ligament) from the fastener hole.

(4) In areas where the presence of a crack would cause load and stress redistribution within adjacent structure, the largest permissible crack size would be that which would reduce the service life or safety limit of the affected structure below the requirements of 3.2.14.

(5) For non-safety of flight structure, this crack size would be the critical crack size for the structural component. (Structural components such as wheels, pylons, bomb racks, etc., may fall into this category.)

In cases where the crack growth analysis approach may not be applicable or verifiable, such as in the case of non-metallic structure and high strength steel landing gear structure, fatigue analysis method shall be used providing that sufficient development test data is generated to demonstrate compliance with the requirements.

VERIFICATION LESSONS LEARNED (A.4.11.1.1)

Two basic types of durability analyses techniques have been employed at various times on aircraft in the inventory. Both classical fatigue analysis with a scatter factor and crack growth durability analysis have been widely employed with adequate amount of test data from the actual structure to establish the analysis parameters.

A.4.11.1.2 Tests.

The following tests shall be performed to show that the airframe structure meets the requirements of 3.11.1.

VERIFICATION RATIONALE (A.4.11.1.2)

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Comprehensive durability tests are required to verify the service life of the airframe. Both development and full-scale testing are required to get an early indication and validation, respectively, of the service life of the structure.

VERIFICATION GUIDANCE (A.4.11.1.2)

Specific guidance for the required testing is contained in A.4.11.1.2.1 and A.4.11.1.2.2. (Also see Guidance for 4.11.1.)

VERIFICATION LESSONS LEARNED (A.4.11.1.2)

A.4.11.1.2.1 Development tests.

Development tests shall be conducted to provide data for establishing design concepts, providing early analysis procedure validation, selecting materials, determining spectrum effects, and validating the critical components durability. Using existing data to meet this requirement shall be justified. Development tests shall include but not be limited to:

a. Element Test. These tests are typically run with sufficient sample size to determine a statistical compensated allowable.

(1) Material selection properties including structural design allowables.

(2) Environmental effects including temperature, moisture, fuel immersion, chemicals, etc.

(3) Fastener systems, fastener allowables, and bonding evaluation.

(4) Process evaluation including all corners of the allowable processing window.

b. Structural Configuration Development Tests. These tests are typically run with a smaller sample size, and as such, the results are used to validate the analytical procedures and establish design allowables. Actual material properties and dimensions should be used when determining correction factors, and the lower range of test results used for design allowables.

(1) Splices and joints.

(2) Panels (basic section).

(3) Panels with cutouts.

(4) Fittings.

(5) Critical structural areas which are difficult to analyze due to complexity of design.

(6) Manufacturing methods evaluation including all acceptable variations such as gaps, pulldown, shimming, etc.

(7) Composite failure modes and strain levels.

(8) Environmental effects on composite failure modes and failure strain levels.

c. Large Component Development Tests. These tests are to allow early verification of the durability capability and producibility of final or near final structural designs of critical areas. The actual number and types of tests will depend upon considerations involving structural risk, schedule, and cost. The large component tests should be of large assemblies or full scale components such as wing carry through, horizontal tail support, wing pivots, landing gear support, complex composites, large structural castings, or any unique design features with design unknowns in:

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(1) Splices and joints.

(2) Fittings

(3) Panels

(4) Stability critical end or edge fixates

(5) Out of plane effects in composites

(6) Post buckled structure

(7) Environmental effects on composite failure modes and failure strain levels.

d. Design Development Testing Approach for Composites. A building block approach to design development testing is essential for composite structural concepts, because of the mechanical properties variability exhibited by composite materials, the inherent sensitivity of composite structure to out of plane loads, their multiplicity of potential failures modes, and the significant environmental effects on failure modes and allowables. Sufficient development testing must be done with an appropriately sized component to validate the failure mode and failure strain levels for the critical design cases with critical temperature and end of life moisture.

VERIFICATION RATIONALE (A.4.11.1.2.1)

Sufficient development test data must be available to substantiate the criteria and assumptions used in the durability analysis, including an evaluation of the sensitivity of the analysis to these assumptions.

VERIFICATION GUIDANCE (A.4.11.1.2.1)

Design development tests should progress from basic material property tests through a series of test specimens with increasing levels of geometry and loading complexity. These tests are intended to provide more information than just indicating whether a given structural detail will likely meet the minimum requirements. In order to verify an analytical failure prediction, both the predicted time to failure and the predicted failure mode must be verified. This implies that at least some of the development tests, with a sufficient level of loading and geometry complexity to accurately simulate the full scale structure, must be tested to failure. The same applies to testing to determine stress level, spectrum, and environmental sensitivities and the failure modes.

The scope of the testing is directly dependent upon the available data base for the materials and structural details of interest.

Other areas that should be considered in the development testing are environmental effects and the influence of manufacturing tolerances. Additional guidance can be found in 4.10.5.1.

For composite structures, the effect of repeated low level impacts on the durability of the structure should be investigated. Hail impact, tool droppage, or the damage caused by walking on the structure may not be apparent but the repeated impact over a given area may affect the durability of the structure. The structure should be zoned according to the likely types of damage that can be incurred and the sensitivity of the durability of the area to these damage sources should be assessed in the development test program. The magnitude and frequency of the impacts to be evaluated should be based on the consideration of the air vehicle over its service life. Additional guidance can be found in 3.11.1. If the durability of an area proves to be sensitive to a repeated damage source, consideration should be given to simulating the damage on the full scale test article to verify the effects of the damage.

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The durability analyses for composites are linked to the development tests. In support of these analyses, it is recommended that the development testing consist of "building blocks" ranging from coupons to elements, subcomponents, and finally components. These building block tests must include room temperature dry laminates. Also, if the effects of the environment are significant, then environmentally conditioned tests must be performed at each level in the building block process. The test articles are to be strain gaged adequately to obtain data on potentially critical locations and for correlation with the full scale static test, and in addition, the test program is to be performed so that environmentally induced failure modes (if any) are discovered. The design development tests are complete when the failures modes have been identified, the critical failure modes in the component tests are judged to be not significantly affected by the nonrepresentative portion of the test structure and the structural sizing is judged to be adequate to meet the design requirements. It is evident from the approach described above that separate tests may be required for the metallic, and mixed metallic and composite structural parts.

For durability test of composite components, the success criteria is somewhat more complicated by the relatively large scatter in fatigue test results and the potential of fatigue damage from large spectrum loads. It has been demonstrated, however, that the durability performance of composites is generally excellent when the structure is adequate to meet its strength requirements. Therefore, the thrust of the durability test must be to locate detrimental stress concentration areas that were not found in the static tests. An approach to achieve this goal is to test the durability components to two lifetimes with a spectrum whose severity accommodates these concerns. When the effects are judged to be significant, durability tests for design development shall be moisture conditioned.

VERIFICATION LESSONS LEARNED (A.4.11.1.2.1)

In past programs durability development testing of coupons, small elements, structural design concepts, and critical components included test lives in excess of the number required in the full-scale durability test (i.e., in excess of four lifetimes for a swing wing bomber and air supremacy fighter and two lifetimes for an air superiority fighter). Tests were designed to insure that meaningful data on cracking and failure modes could be obtained. There has been a recent tendency to cut short the test lives for durability development tests to two lifetimes followed by deliberate preflawing and continuing as damage tolerance tests. In many cases, limiting the durability test can restrict the amount of development data obtained from the test. In most cases, the location of cracking and extent of cracking is of more value than the data obtained from deliberately placed flaws. Some specimens have failed to produce any cracking in two lifetimes and no growth of deliberately placed flaws in one lifetime. Such tests have failed to meet their objectives. For this reason, test planning should include clear test objectives with the goal to test until natural cracking occurs.

A.4.11.1.2.2 Durability tests.

A complete airframe or approved alternatives shall be durability tested to show that the airframe structure meets the required service life specified in 3.2.14. Critical structural areas, not previously identified by analyses or development tests, shall be identified. Any special inspection and modification requirements for the service airframe shall be derived from these tests.

VERIFICATION RATIONALE (A.4.11.1.2.2)

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The timely completion of full-scale durability testing is essential to determine if the service life requirements are satisfied and that any required structural modifications can be identified and incorporated in the structure prior to significant production milestones.

VERIFICATION GUIDANCE (A.4.11.1.2.2)

Specific guidance for the individual requirements concerning the full-scale testing are contained in the following subparagraphs. See 4.10.5.2 and subparagraphs for additional full-scale test guidance.

VERIFICATION LESSONS LEARNED (A.4.11.1.2.2)

a. Test article. The test airframe shall be structurally identical to the operational airframe. Any differences, including material or manufacturing process changes, will be assessed for durability impact. Significant differences will require separate tests of a production article or selected component to show that the requirements of 3.11 are met for the operational airframe.

VERIFICATION RATIONALE (A.4.11.1.2.2.a)

In order to demonstrate that service life requirements are satisfied for the production configuration, it is necessary to test an airframe which is identical to the final production design.

VERIFICATION GUIDANCE (A.4.11.1.2.2.a)

The timing of the durability test, as indicated in 4.11.1.2.2.b, usually necessitates the fabrication of the test airframe prior to the final production drawing release. To minimize differences between the test airframe and the production airframe structure, careful attention must be paid to coordinating the timing of the development tests, production drawing releases, and test article fabrication. Differences which are deemed significant must be demonstrated to be in compliance with the requirements of this specification by analysis and test as approved by the procuring agency.

VERIFICATION LESSONS LEARNED (A.4.11.1.2.2.a)

Generally, components such as landing gear, some empennage structure, or pylons can be successfully tested as components. It is usually necessary, and most cost effective, to test the wing and fuselage as an assembly to insure that the effects of interface loadings are accounted for properly.

b. Test schedule.

(1) The airframe durability test shall be performed such that one lifetime of durability testing plus an inspection of critical structural areas in accordance with 4.11.1.2.2.e shall be completed in time to support ___________.

(2) Two lifetimes of durability testing plus an inspection of critical structural areas in accordance with 4.11.1.2.2.e shall be completed in time to support _____________________.

VERIFICATION RATIONALE (A.4.11.1.2.2.b)

It is necessary to mesh durability testing with major production milestones to minimize the impact of major redesign and retrofit efforts necessitated by the discovery of structural deficiencies during the test.

VERIFICATION GUIDANCE (A.4.11.1.2.2.b)

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(1) One lifetime of testing plus the indicated inspections should be completed prior to a production go-ahead decision.

(2) The second lifetime of testing plus the indicated inspections should be completed prior to the delivery of the first production aircraft.

VERIFICATION LESSONS LEARNED (A.4.11.1.2.2.b)

A fighter development program has demonstrated that these test timing requirements can be accommodated in a reasonable development effort and the advantages to the government of this test before buy approach are clearly evident.

c. Test evaluation. All test anomalies which occur within the duration specified in 4.11.1.2.2.f, to include areas which have initiated cracking or delamination as determined by post test teardown inspection, shall be evaluated for production and retrofit modifications, particularly with respect to those anomalies which would impose undue inspection burden for carrier based aircraft. Test anomaly analyses must be correlated to test results, and the adjusted analyses must show that the test anomalies meet the durability requirements of 3.11 and the damage tolerance requirements of 3.12 (if applicable). Modifications shall also be shown to satisfy durability and damage tolerance requirements either by test or analysis at the discretion of the acquisition activity.

VERIFICATION RATIONALE (A.4.11.1.2.2.c)

Full scale durability test results form the basis of actions required to achieve full airframe service life. These actions may take the form of production/retrofit modifications or in-service inspections.

VERIFICATION GUIDANCE (A.4.11.1.2.2.c)

If the durability analysis is confirmed by the full scale test, no structural anomalies will occur and, therefore, no specific actions (e.g. inspections, modifications) to achieve full service life are required. However, structural anomalies identified during the two lifetime test, or determined to have initiated during that period as part of the subsequent teardown inspection, must be evaluated with respect to safety, operational and economic impacts. All findings which raise concern for safety, functional impairment or inspection difficulty/implementation, particularly for carrier based aircraft, are the responsibility of the manufacturer and require modification or repair in order that fleet airframes achieve full service with minimum impact to operations, cost, and planned inventory. All other findings should be documented and evaluated with regard to disposition (i.e. no action, inspection, modification) with implementation subject to the discretion of the procuring agency.

When findings occur during test, it is clear that the durability analysis must be corrected such that the analytical prediction will correlate to the test finding. The corrected analysis must show compliance with the durability requirements of 3.11 and the damage tolerance requirements of 3.12, if applicable. If modifications are required, they too must meet durability and damage tolerance requirements by test or analysis at the discretion of the procuring activity.

VERIFICATION LESSONS LEARNED (A.4.11.1.2.2.c)

d. Test spectrum. The test spectrum shall be derived from and be consistent with 3.2.14.6. and 3.11. Truncation, elimination, or substitution of load cycles is allowed subject to approval by the acquisition activity.

VERIFICATION RATIONALE (A.4.11.1.2.2.d)

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The purpose of the durability test is to substantiate the service life of the airframe structure. In order to identify critical areas and protect against planned inventory shortfalls or operational disruptions which can be caused by weight and usage variations, the test loading and environment must reflect the requirements 3.2.14.6.

VERIFICATION GUIDANCE (A.4.11.1.2.2.d)

The test spectrum should be derived from the requirements defined in 3.2.14.6. The results of the development tests required in 4.11.1.2.1 should provide additional guidance. The level of chemical and thermal environmental simulation necessary during the test should be defined during development testing. High and low load truncation levels should be evaluated based on the effects on durability (and damage tolerance) limits and substantiated by developmental testing. Proof testing or residual strength testing prior to the completion of two lifetimes of durability testing should be avoided unless the air vehicle will be proof tested in service.

VERIFICATION LESSONS LEARNED (A.4.11.1.2.2.d)

The problem of developing a full-scale test spectrum, and the associated analysis spectrum, has existed on every aircraft development program. The use of average parameters, such as gross weight, altitude, airspeed, etc., within a given segment of the flight envelope to determine external loading generally leads to a benign spectrum which does not adequately interrogate the structure. A maximum amount of attention should be focused on spectrum development to obtain the most realistic spectrum possible consistent with the requirements of 3.2.14.

e. Inspections. Inspections shall be performed as an integral part of the durability tests and at the completion of testing. These inspections shall consist of design inspections, special inspections, and a post-test complete teardown inspection after test completion.

VERIFICATION RATIONALE (A.4.11.1.2.2.e)

Thorough in-test and post-test inspections are required to completely evaluate whether the durability requirements of 3.11 have been satisfied. These inspections are an essential part of the assessment to establish the service life, and supporting actions, for the structure. In addition, other valuable information is derived, such as the identification of accessibility problems, unanticipated cracking, and the location of small cracks which can be used in the damage tolerance testing or analysis. A thorough teardown inspection immediately after test completion will assure that information regarding the need for production redesign and/or service retrofit is obtained early in the production program to minimize the number of aircraft affected.

VERIFICATION GUIDANCE (A.4.11.1.2.2.e)

Durability test inspections need to be established which identify what, how, and when inspections are to be performed. The frequency of inspection should increase as the test progresses. Inspections shall be conducted after one lifetime of testing. This inspection, as a minimum, shall include all areas defined as critical and should include partial disassembly and fastener removal as necessary to accurately assess the condition of the structure. The inspection after two lifetimes of testing shall be as thorough as possible taking into consideration possible continued testing. The final inspection on the test article shall include sufficient disassembly and detailed inspection to identify any unanticipated durability problem areas in the structure. If the teardown inspection is to follow completion of damage tolerance tests or third lifetime durability tests, the test procedure shall specify the procedures which will be used to "mark" the end of two lifetime durability testing. Teardown inspection procedure shall be developed. Items such as removing of skins, door panels, selective fasteners, all the primary structure, etc. shall be included.

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VERIFICATION LESSONS LEARNED (A.4.11.1.2.2.e)

A full scale test was completed on a fighter aircraft and only limited non-destructive inspections were conducted on critical areas. The test article was stored for potential future testing if the usage spectrum was more severe than design. Several years later, service aircraft experienced cracking in the wing spars resulting in a maintenance burden for the USAF. The test article in storage was examined and found to contain similar cracks as the service aircraft. If the test article had been thoroughly inspected, a relatively inexpensive production redesign could have avoided substantial maintenance costs.

f. Duration. A minimum of two lifetimes of durability testing except as noted below is required to certify the airframe structure. A third lifetime testing shall be performed to support damage tolerance requirements, repair/modification changes, usage changes, and life extension potential.

(1) Ship based aircraft nose landing gear and backup structure shall have _____ lifetimes of durability testing.

(2) Ship-based aircraft main landing gear and backup structure shall have _____ lifetimes of durability testing.

(3) Land based aircraft nose and main landing gear shall have _____ lifetimes of durability testing.

(4) High strength parts analyzed by fatigue analysis shall have _____ lifetimes of durability testing.

(5) Others: __________.

VERIFICATION RATIONALE (A.4.11.1.2.2.f)

It is necessary to plan, budget, and test beyond the required service life to provide a margin against normal variations in manufacturing, material, properties, loads, and usage characteristics.

VERIFICATION GUIDANCE (A.4.11.1.2.2.f)

A minimum of two lifetimes of full scale durability testing must be conducted to identify the hot spots and damage tolerance critical locations. However, three lifetimes of the test program shall be planned, budgeted, and included in the proposal. The third lifetime of testing shall be evaluated on the following options:

a. Continued durability combined with damage tolerance testing.

b. Continued durability testing for the purpose of life extension and/or modification verifications.

c. Residual strength testing to failure.

d. Damage tolerance testing, fail-safe testing, and battle damage tolerance testing.

e. Usage spectrum sensitivity testing.

At the conclusion of the full scale durability testing, the final teardown inspection shall be conducted.

To compensate for the complexity of the different aircraft systems such as bomber, fighter, and trainer, the test duration requirements may vary from system to system. For landing gear, landing gear back-up structure, high strength structure, and special structure, the specified test factor on design life shall be between 2.0 and 4.0 as a function of spectrum severity,

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consequence of failure, material damage tolerance characteristics, weight/cost trades, etc, subject to the approval of the procuring activity. For example, the single point failure mode and catastrophic consequences of failure during the catapult evolution of ship based operations mandates additional safety margin in both the nose landing gear and the corresponding airframe back-up structure have a four lifetime durability testing requirement to a spectrum which includes catapults, landing and related ground events. Carrier-based aircraft main landing gear and back-up structure, however, have previously implemented a two lifetime requirement as a function of the spectrum severity and less catastrophic implications of failure. Land-based aircraft landing gears have previously implemented a four lifetime requirement as a result of spectrum severity, material damage tolerance, or analysis considerations. A test duration of less than four lifetimes may be programmed if test spectrum is more severe than design spectrum. (Reference Lincoln, "Assessment of Structural Reliability from Durability Testing", ICAF Conference 1993.) Gear tests may be conducted either on fixtures or the full scale test article, and may also be the same gear used for the drop test program, with credit accounted for the number and severity of drop test landing events.

VERIFICATION LESSONS LEARNED (A.4.11.1.2.2.f)

The use of the durability test article for the continued durability combined with damage tolerance verification testing has proven to be the best option for continued testing. Besides the obvious cost advantages, additional durability information is obtained and naturally developed cracks can provide significant information to aid in the damage tolerance evaluation. A large aircraft full scale durability test program was planned to have two lifetimes of durability testing followed by one lifetime of damage tolerance testing on the same test article. The contractor did not submit a third lifetime testing proposal in the original proposal. However, the third lifetime of full scale durability testing was recommended late and tremendous time and effort had to be spent to accomplish the required task. If a third lifetime of testing was planned and budgeted in the original proposal, the implementation would have been much easier and cost effective.

A.3.11.2 Corrosion prevention and control.

The airframe shall operate in the corrosion producing environments and conditions of 3.2.16. Corrosion (including pitting, stress corrosion cracking, crevice, galvanic, filiform, and exfoliation) which affects the operational readiness of the airframe through initiation of flaws which are unacceptable from a durability, damage tolerance, and residual strength viewpoint shall not occur during the service life and usage of 3.2.14. Corrosion prevention systems shall remain effective during the service life and usage of 3.2.14 in the environments and under the conditions of 3.2.16 for the periods indicated below. Specific corrosion prevention and control measures, procedures, and processes must be identified and established commensurate with the operational and maintenance capability required of the airframe. Finishes shall also comply and be compatible with the requirements of 3.2.20. The following additional requirements apply:

a. Structure which is difficult to inspect, repair, or replace, or places an undue economic burden on the user, must comply with the requirements of 3.2.14 for the service life of the airframe.

b. Other structure for the period of ___________________.

REQUIREMENT RATIONALE (A.3.11.2)

Corrosion prevention systems must be effective for minimum periods of service usage to minimize the life cycle costs associated with corrosion damage inspection and repair. A

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systematic and disciplined approach for addressing corrosion prevention and control must be established early in the development life cycle.

REQUIREMENT GUIDANCE (A.3.11.2)

Define the periods of usage which other structure must withstand without incurring corrosion damage. A period of time less than the airframe service life may be specified, such as a percentage of the service life requirements of 3.2.14 or a period of time equivalent to regularly scheduled airframe inspections, field maintenance activities, or programmed depot maintenance intervals.

MIL-STD-1568 should serve as a baseline approach to addressing corrosion control and prevention and should be deviated from only with appropriate supporting engineering justification.

The protection of the aircraft and its component parts from corrosion should be in accordance with MIL-F-7179 and NAVMAT-P-4855-2. The corrosion protection requirements and concepts should be applied during system definition, design, development, and production. Emphasis should be placed on correcting historically corrosion prone areas (e.g., bushed flight control surface hinges/structural attachments) during system definition, design, development, and production. The design of the airframe, systems, and the subsystems should preclude the intrusion and retention of fluids. Sharp corners and recesses should be avoided so that moisture and solid matter cannot accumulate to initiate localized attack. Adequate ventilation should be provided in all areas to prevent moisture retention and buildup. Cleaning, surface treatment, and inorganic coatings for metallic materials should be in accordance with MIL-S-5002. Sulfur dioxide salt spray/fog testing should be conducted in accordance with ASTM G85.A4 and for a minimum period of 500 hours. Fasteners should be wet installed with sealant or non water-bourne primer.

Use of dissimilar metals (as defined by MIL-STD-889) in contact should be limited to applications where similar metals cannot be used due to peculiar design requirements. When it is necessary to use dissimilar metals in contact, the metals should be adequately protected against galvanic corrosion as per MIL-STD-889. Metals such as aluminum alloys that are prone to galvanic attack in contact with graphite composites should also be protected as per MIL-STD-889 with either coatings and sealants and/or barrier materials such as cocured fiberglass or scrim cloth, whichever is appropriate. Aluminum fasteners, stainless steel fasteners, and cadmium plated fasteners should not be used in contact with graphite composites. Items electrically bonded or used for electromagnetic interference hardening should be sealed to prevent moisture intrusion. Frequently removed items or items that are not practical to seal should be of similar materials. Emphasis should be placed on using fasteners versus bare metal to metal contact to achieve bonding. During the structural design and material/process selection, consideration should be given to various design alternatives which preclude the traditional galvanic corrosion problems created by dissimilar metal bushings (e.g., beryllium copper, aluminum bronze) installed in aluminum structure. Consideration should be given to the avoidance of using removable graphite composite doors/panels fastened to aluminum alloy substructure, particularly on upper surfaces where moisture/salt spray can potentially migrate through the fastener holes and cause corrosion of the aluminum substructure.

All designs should include provisions for the prevention of water, condensation, and other unwanted fluid accumulation and entrapment. Actual aircraft configuration and attitude should be considered in addition to component design. All metal sections should preferably be open sections to permit drainage, inspection, cleaning, and refinishing of section surfaces. Closed sections, where used, should include provisions for drain holes to allow free drainage of accumulated fluids which can enter by various methods. Drain holes should be located to effect

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maximum drainage of unwanted fluids. All drainage should be through meniscus free drain holes. Unless otherwise specified, struts and welded tube structures should provide for airtight closure by welding, anti-corrosion treatment, and subsequent positive sealing. This is particularly applicable to steel struts and tube structures which should be welded easily. Mere convenience of fabrication is insufficient reason for not sealing steel tubes. Tubes or struts that cannot be closed readily by welding, should be left open in a manner to provide for free drainage, ventilation, inspection, and refinish. End fittings used with open tubing should not form pockets which may collect moisture. Cork seals, dams, and metal end plugs machined to fit, should not be used.

All crevices in exterior locations and faying surfaces with edges leading to an exterior surface should be filled or sealed with MIL-S-81733 sealant.

REQUIREMENT LESSONS LEARNED (A.3.11.2)

Corrosion costs are extremely high. This problem can be primarily attributed to poor material choices during the development stages and faulty design and manufacturing processes. An example of a poor material choice is the corrosion prone 7075-T6 used in some aircraft, which has resulted in maintenance problems. Stress corrosion cracking and galvanic corrosion are two severe problems which often stem from manufacturing processes and they may not show up until late into the service life of the system.

In the future, aircraft will be forced to fly more hours than initially expected. In addition, funds available for corrosion maintenance will be reduced. These factors give added significance to the corrosion problem.

Methods of corrosion control shown to be effective include proper materials selection (specifically the use of age stabilized aluminum alloys to preclude exfoliation corrosion and stress corrosion cracking), manufacturing processes to preclude built-in stresses during fabrication and assembly operations and those which inhibit rust, use of high quality corrosion protection systems selected on the basis of the anticipated environments, and the frequent use of corrosion inspection techniques. A ground attack, an air supremacy fighter, an air superiority fighter, and some transports which have been overseen by corrosion boards, have had significant decreases in required corrosion maintenance compared to other systems not overseen by corrosion boards.

MIL-STD-1568 provides corrosion prevention and control guidance on materials and processes selection criteria, material systems and processes performance data, standard design practices, repair/maintenance practices and considerations. Corrosion prevention and control must be addressed early in the development process to insure that optimum materials and protection systems are incorporated and that all disciplines involved in airframe design development production and maintenance are addressed.

Several cases of corrosion damage occurring on in-service aircraft where fasteners were not wet installed with sealant or primer at the manufacturer. The corrosion was initiated by water and salt contamination intrusion around panel retaining fasteners. The lack of wet installation with sealant or primer has resulted in corrosion damage.

Aircraft with beryllium copper or aluminum bronze bushings installed in aluminum structure has resulted in galvanic corrosion.

Several magnesium components have been replaced with aluminum components due to the high scrap rates caused by corrosion.

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A.4.11.2 Corrosion prevention and control.

Corrosion prevention and control measures including the following elements shall be established and implemented in accordance with _____________ to verify that the requirements of 3.11.2 are met.

a. The criteria for the selection of corrosion resistant materials and their subsequent treatments shall be defined. The specific corrosion control and prevention measures shall be defined and established as an integral part of airframe structures design, manufacture, test, and usage and support activities.

b. Organic and inorganic coatings for all airframe structural components and parts, and their associated selection criteria shall be defined.

c. Procedures for requiring drawings to be reviewed by and signed off by materials and processes personnel shall be defined.

d. Finishes for the airframe shall be defined. General guidelines shall be included for selection of finishes in addition to identifying finishes for specific parts, such that the intended finish for any structural area is identified.

e. The organizational structure, personnel, and procedures for accomplishing these tasks shall be defined and established.

VERIFICATION RATIONALE (A.4.11.2)

Corrosion prevention measures are required to minimize the impact of corrosion problems on the durability and maintenance costs over the expected lifetime of the aircraft.

VERIFICATION GUIDANCE (A.4.11.2)

The entire process (organizational structure, approach, techniques, and plans) should be established and implemented beginning with concept definition activities. The criteria for the section of corrosion resistant materials and their subsequent treatments, such as shot peening, shall be defined. The guidance contained in MIL-STD-1568 should serve as the baseline approach for addressing materials/processes and corrosion requirements and should be deviated from only with appropriate supporting engineering justification. The development and maintenance of a corrosion prevention and control plan, finish specifications, and system peculiar corrosion control technical order in accordance with the guidance provided in MIL-STD-1568 should be considered. To ensure that the approach to corrosion prevention and control is well coordinated and addresses all phases of the acquisition, a Corrosion Prevention Advisory Board (CPAB) should be established in accordance with the guidance outlined in MIL-STD-1568.

VERIFICATION LESSONS LEARNED (A.4.11.2)

Corrosion Assistance Teams on various aircraft programs have been successful in eliminating corrosion problems in later production aircraft. The corrosion problems were eliminated by changes in design and manufacturing practices. In addition, the correction was incorporated in the in-service aircraft.

A.3.11.3 Thermal protection assurance.

Thermal protection systems shall remain effective during the service life and usage of 3.2.14 in the environments and under the conditions of 3.2.16 for the periods indicated below. Finishes shall also comply and be compatible with the requirements of 3.2.20 and 3.11.2.

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a. Structure which is difficult to inspect, repair, or replace for the service life of the airframe.

b. Other structure for the period of ___________________.

REQUIREMENT RATIONALE (A.3.11.3)

Thermal protection systems must be designed to be effective for minimum periods of service usage to prevent excessive maintenance and repair costs over the life of the air vehicle.

REQUIREMENT GUIDANCE (A.3.11.3)

Define the time periods of usage which other structures must withstand without incurring damage. A lifetime less than the airframe service life may be specified, such as a percentage of the service life requirements of 3.2.14 or a period equivalent to that for regularly scheduled airframe inspections or replacement of parts.

REQUIREMENT LESSONS LEARNED (A.3.11.3)

4.11.3 Thermal protection assurance.

The following tests and analyses shall be performed to verify that the thermal protection systems of the airframe meet the requirements of 3.11.3: _____________________.

VERIFICATION RATIONALE (A.4.11.3)

It is necessary to validate the durability of thermal protection systems to prevent the occurrence of costly maintenance problems.

VERIFICATION GUIDANCE (A.4.11.3)

For each area of the structure where there is a durability requirement established in section 3.11.3, analyses and tests need to be defined to insure that the requirements of 3.11.3 are satisfied. The duration of the required tests should be defined to provide adequate life margins considering the cost of the protection system and associated maintenance costs.

VERIFICATION LESSONS LEARNED (A.4.11.3)

A.3.11.4 Wear and erosion.

The function of structural components, elements, and major bearing surfaces shall not be degraded by wear under the service life and usage of 3.2.14 for the periods indicated below. Leading edges, radomes, housings, and other protrusions shall not be degraded by erosion under the service life and usage of 3.2.14 for the periods indicated below. Bearings shall also comply and be compatible with the requirements of 3.3.13 and 3.11.2.

a. Structural surfaces which move for _______________.

b. Structural and maintenance access panels and other removable parts for _______________.

c. Doors and ramps for _______________.

d. Other structure for _______________.

e. Leading edges for _______________.

f. Radomes for _________________.

g. Housings for _________________.

h. Other protrusions for __________________.

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REQUIREMENT RATIONALE (A.3.11.4)

Structural components which are subjected to wear under normal operating conditions must be designed to withstand this environment for minimum periods of usage.

REQUIREMENT GUIDANCE (A.3.11.4)

Define the time periods of usage which functional structures must withstand without incurring wear damage. A lifetime less than the airframe service life may be specified, such as a percentage of the service life requirement of 3.2.14 or a period equivalent to that for regularly scheduled airframe inspections or replacement of parts.

The design and manufacture of aircraft should include practices to minimize damage by wear and erosion. Wear and erosion prevention practices should be followed on applicable surfaces of metals, polymers, elastomers, ceramics, glasses, carbon fabrics, fibers, and combinations or composites of these materials. Provision should be made to eliminate or minimize combinations of erosive, corrosive, and thermal effects on structure near heater and engine bleed air, engine exhaust, rocket and missile exhaust, and in the wake of such exhaust gases. In no case should there be direct flame impingement from missiles and rockets on aircraft surfaces unless such surfaces are suitably protected by a coating or device.

Wear. Wear prevention practices should be applied to all load bearing and load transfer interfaces. These areas include fastened, riveted, bolted, and keyed joints; bearings, races, gears, and splines; contact surface of access doors and panels, hinges and latches; contact point of cables, ropes, and wires as well as contact areas between metallic and polymeric strands; interference fits; friction clamps, contact points of springs; sliding racks and pulley surfaces; and other surfaces subject to wear damage. Materials, surface properties, system friction and wear characteristics, liquid and solid lubrication systems, surface treatments and coating, contact geometry, load, relative motion, and service environment should be fully substantiated and documented.

Erosion. Erosion prevention practices should be applied to all surface areas including leading edges, radomes, housings, and other protrusions as well as to surfaces exposed to particle impingement during take-offs and landings.

Lubrication. Provisions should be made for lubrication of all parts subject to wear. Flight control system servocylinder attachment bearings should not require lubrication during the life of the aircraft except for the leading edge flap transmission. The selection of lubricants (oil, greases, solid film coatings, anti-seize compounds, heat transfer fluids, coolants, and hydraulic fluids) should be in accordance with MIL-HDBK-275 as specified in MIL-STD-838. The fire resistant synthetic hydrocarbon hydraulic fluid, MIL-H-83282, should be used as the aircraft hydraulic fluid. The number of different lubricants required should be kept to a minimum by using multipurpose lubricants such as the wide temperature general purpose grease, MIL-G-81322 whenever possible, without compromising aircraft performance and reliability. All lubrication fittings should be readily accessible. Components in highly loaded/dynamic and potentially corrosive applications (e.g., landing gear, arresting gear) should make maximum use of lubrication fittings, vice other forms of lubricant. Parts subject to immersion in sea water should be designed so as to exclude sea water from bearings.

REQUIREMENT LESSONS LEARNED (A.3.11.4)

Accessibility to areas that may be subject to wear should be a primary development consideration because wear is difficult to predict and may only be identified after extended periods of actual service usage. In Desert Storm, fixed wing and helicopter rotorblade leading edge polyurethane and brush on coatings do not provide adequate protection from sand

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erosion. More durable erosion resistant coatings should be developed without compromising performance characteristics. In addition, the fine sand caused severe crazing of aircraft canopies during storage and fleet use. High sunlight/heat was damaging components in the cockpit interior.

High failure rates of helicopter tail rotor counterweight arm bearings were experienced due to the fine sand intrusions. In the past, helicopter main landing gear skids were not designed for hard landings in the sand.

A.4.11.4 Wear and erosion.

The following tests and evaluation shall be performed to show that the airframe structure meets the requirements of 3.11.4: _____________.

VERIFICATION RATIONALE (A.4.11.4)

In order to insure that minimum durability requirements are satisfied by components subject to wear in service usage, test verification is required.

VERIFICATION GUIDANCE (A.4.11.4)

The specific test and test duration for each requirement identified in section 3.11.4 should be defined. The test durations established should provide adequate margins to cover normally expected variations in manufacturing tolerance and in intended usage.

VERIFICATION LESSONS LEARNED (A.4.11.4)

Testing to evaluate wear should be structured such that acceptable and unacceptable limits on the amount of wear damage for a given component can be defined and the appropriate information incorporated into the maintenance technical instructions.

A.3.11.5 Special life requirement structure.

The following structural components shall comply with 3.11.1 and 3.11.2 for the periods indicated:

a. Limited life structure _________________.

b. Extra life structure. __________________.

REQUIREMENT RATIONALE (A.3.11.5)

Any structural component whose performance can be degraded under the expected operational usage must be able to withstand the expected environment for minimum periods of usage.

REQUIREMENT GUIDANCE (A.3.11.5)

It may be cost effective and result in a more efficient airframe structure if some components are repaired or replaced periodically. Define the time periods of usage which these structural components must withstand without incurring degraded operation. A lifetime less than the airframe life may be specified, such as a percentage of the design life requirements of 3.2.14 or a period equivalent to that for regularly scheduled airframe inspections or replacement of parts. The provisions of 3.11.4 should be considered when selecting components as special life requirement structures. Special consideration should be given to easily accessible non-safety of flight structure.

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REQUIREMENT LESSONS LEARNED (A.3.11.5)

In the design of high strength structure, the use of fracture mechanics technique cannot provide adequate solution to predict structural lives. Other methods, such as strain life analysis, require a scatter factor of four to maintain the acceptable reliability.

A.4.11.5 Special life requirement structure.

The following analyses and tests shall be performed to show that airframe meets the requirements of 3.11.5: _____________.

VERIFICATION RATIONALE (A.4.11.5)

The durability of any structural component whose function may be degraded in service usage needs to be substantiated by analyses and tests.

VERIFICATION GUIDANCE (A.4.11.5)

Specify the type and duration of the analyses and testing necessary to validate the durability requirements of 3.11.5. Also see Verification guidance (A.3.11.5).

VERIFICATION LESSONS LEARNED (A.4.11.5)

To account for scatter factor used in the analysis and to maintain the acceptable structural reliability, high strength structures have been tested for four lifetimes of the average spectrum.

A.3.11.6 Nondestructive testing and inspection (NDT/I).

NDT/I shall be utilized during the design, development, production, and deployment phases of the program to assure that the system is produced and maintained with sufficient structural integrity to meet performance requirements. Other requirements apply as appropriate: ___________.

REQUIREMENT RATIONALE (A.3.11.6)

NDT/I is the only method available to screen materials and structures for harmful defects.

REQUIREMENT GUIDANCE (A.3.11.6)

NDT/I has the potential for assuring that materials and newly manufactured structures meet design quality levels. Additionally, it is useful for evaluating the structural integrity of in-service hardware when conditions warrant (i.e. change in usage or suspected damage). NDT/I requires engineering analysis to identify the appropriate technology for use and qualified personnel for application. NDT/I is most effective when detailed structural analysis has identified structurally critical locations, load paths, and quality criteria necessary for meeting performance and life requirements.

Approved NDT/I methods. MIL-I-6870 identifies the process control documents for a variety of NDT/I methods. Other methods exist that are not controlled with a DOD process standard or specification and may also be used. Selection of the NDT/I methods and development of procedures for use are engineering functions and require understanding of the following factors:

a. Nature of the defects to be detected. This includes size, shape, location, orientation, and any other properties which will affect detectability with the methods to be used.

b. NDT/I reliability. For noncritical structure, adequate reliability is assured when the NDT/I is performed by qualified personnel following procedures approved by the appropriate

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authority. For critical structure, that is structure subject to fracture control considerations, adequate reliability may require more than adherence to approved procedures by qualified personnel. MIL-STD-1823 (draft - to be published) provides guidance on the demonstration of NDT/I reliability when more than normal reliability is required.

Contractor NDT/I process documents. Both government and industry process standards and specification are general in nature and do not contain sufficient detail to address applications to specific hardware in specific facilities. Consequently, contractor process documents must be available which describe how the general requirements of the government and industry documents are implemented in the contractor's facility for the system under procurement.

Acceptance criteria (new manufacture). Historically, acceptance criteria for products such as castings and composites, and processes such as welding, have been extremely conservative. They were developed initially as workmanship criteria, i.e. how well can a part be reasonably made, rather than performance criteria, i.e. how well must a part be made to meet a specific performance requirement. They were adopted after the workmanship criteria were found to result in satisfactory performance in qualification testing. Using excessively conservative criteria can result in significant schedule delays as well as costs. Often the added expense and time required to test (qualification) a product that possesses less than good workmanship features can result in significant cost and time savings in production. These criteria selected must be substantiated by performance tests and, additionally, demonstrated that the selected NDT/I and/or testing methods will be effective.

Test articles. Specimen, component, and full scale tests are used to establish material properties and demonstrate that the design meets system performance requirements. A side benefit of such tests is that they can indicate where the "weak structural links" exist if judicious use of NDT/I is used to monitor the test articles either during or after the testing, or both. Knowledge of the "weak links" can be invaluable when in-service usage exceeds the design usage.

Inspectability, manufacturability, and design. One consideration that is sometimes overlooked by the design function is manufacturability. Weldments and critical composite structures can be particularly susceptible. The non-manufacturability of the design becomes apparent when the hardware is submitted for inspection. NDT/I engineering must be able to interface with the design and manufacturing functions to prevent non-manufacturable design from serious consideration.

Composites. Structures continuing composites present different quality problems than metallic structures. Generally, the size of discrete defects that are considered harmful in composites will be larger than those for metallic structures. However, composites can contain a distributed defect, porosity, not considered significant in metallic structures. Composite porosity can be significant in thick laminate and may be an indicator of "non-manufacturability". As with other NDT/I procedures, capable NDT/I engineering is required to assure adequacy when composite porosity is a defect of concern.

REQUIREMENT LESSONS LEARNED (A.3.11.6)

A fighter aircraft, designed for 4000 flying hours, crashed in less than 200 flying hours. The crash was caused by a large manufacturing defect in the wing structure. NDT/I analysis revealed that the NDT/I procedures were incapable of detecting this particular flaw as well as potentially equally dangerous flaws in the majority of the primary structure of the aircraft. This was a direct result of a breakdown of the NDT/I function during design, testing, and production of the system. Specifically, the NDT/I procedures used were never demonstrated to be effective in detecting flaws in many critical locations and orientations.

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A.4.11.6 Nondestructive testing and inspection (NDT/I).

The NDT/I engineering and application efforts during design, testing, and production shall be documented.

VERIFICATION RATIONALE (A.4.11.6)

Documentation is required to provide an audit trail so that the adequacy, thoroughness, and completeness of NDT/I engineering and application efforts can be determined by the contractor's system program management as well as the customer.

VERIFICATION GUIDANCE (A.4.11.6)

MIL-I-6870 describes the detail necessary for the system NDT/I plan which provides the necessary documentation for the engineering efforts. The individual process control documents, either government, industry, or company, describe the detail required for documentation of the application efforts, including records.

NDT/I Manuals. Delivery of the first system into service must be accompanied with manuals that detail when, how often, and how the system is to be inspected for service induced damage. The manuals should include NDT/I methods and their applications as appropriate. As an example, structure subject to impact damage such as leading edges and leading gear should be addressed in the manual. The primary inspection method should be visual for evidence of damage. Determination of the actual presence and/or extent of damage should then be accomplished with the appropriate NDT/I procedures as described in the manuals. As the system ages, the manuals shall be upgraded to contain procedures for the detection of damage found to be appropriate for that system.

NDT/I Advisory Board. An NDT/I Advisory Board containing government and contractor personnel with the appropriate technical skills can provide a very effective way of bringing corporate government knowledge to the contractor for use in the system design, testing, and production functions. They can also provide excellent means for tracking the progress of NDT/I engineering efforts on the program by both contractor and government program management personnel.

VERIFICATION LESSONS LEARNED (A.4.11.6)

A.3.12 Damage tolerance.

The damage tolerance capability of the airframe shall be adequate for the service life and usage of 3.2.14 Safety of flight and other selected structural components of the airframe shall be capable of maintaining adequate residual strength in the presence of material, manufacturing and processing defects and damage induced during normal usage and maintenance until the damage is detected through periodic scheduled inspections. All safety of flight structure shall be categorized into one of two categories, either slow crack growth or fail-safe. Single load path structure without crack arrest features shall be designated as slow crack growth structure. Structures utilizing multiple load paths and crack arrest features shall be designated as slow crack growth or fail-safe if sufficient performance and life cycle cost advantages are identified to offset the burdens of the appropriate inspectability levels of 3.12.2.2 or 3.12.2.3. These requirements apply to metallic and nonmetallic structures, including composites, with appropriate distinctions and variations as indicated. Damage tolerance material properties shall be consistent and congruent with those properties of the same material, in the same component, used by the other structure's disciplines. See 3.2.19.1. Damage tolerance requirements shall also be applied to the following special structural components:

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a. Doors, ramps, and mechanisms (A.3.3.1, A.3.3.2 and A.3.3.3).

b. Nuclear weapons support and suspension structure (A.3.3.16).

c. Other ____________________.

REQUIREMENT RATIONALE (A.3.12)

Air Force experience has demonstrated that designing and qualifying a structure for durability is necessary, but not sufficient, to insure the safety of flight of an air vehicle structure. Damage tolerance and verification requirements, as originally defined in MIL-STD-1530 and MIL-A-83444, were established to define minimum damage tolerance capabilities for all safety of flight structure.

REQUIREMENT GUIDANCE (A.3.12)

These damage tolerance requirements apply to all safety of flight structure including previously qualified structure that is subjected to different operational usage or structural modification. The requirements of this paragraph and subparagraphs apply to all structural material systems except as noted. Other mission essential structural components are to be included under the damage tolerance requirements if the failure of the component resulting from material, manufacturing, and processing defects or in-service damage would severely impact operational capability. The types of structure that should be considered are weapon and engine pylons, avionics pods, external fuel tanks, landing gear structure, and control surfaces. The inclusion of such components should be a specific program decision.

Multiple load path, fail-safe structure is the preferred structural concept. A durable fail-safe structure provides maximum protection from external damage sources, such as combat or FOD; in addition it provides certain distinct advantages if the requirement for life extension arises.

REQUIREMENT LESSONS LEARNED (A.3.12)

Prior to the incorporation of damage tolerance requirements by the Air Force, safety of flight was considered to be adequately assured by strength factors of uncertainty and by scatter factors on fatigue life. As performance requirements increased and technology advanced, the use of higher strength materials at higher stress levels became more prevalent. These high performance structures while approaching the ideal zero margin of safety goal, also resulted in structures that had a zero margin for error in material properties, manufacturing procedures, and inspection capability. A classic example of this situation is the case of the wing pivot fitting on a swing wing fighter. Here the use of a high strength, low toughness steel, resulted in a design that was sensitive to small defects and necessitated an expensive in-service proof test program to maintain safety of flight of the fleet. An air superiority fighter was the first operational aircraft to be designed to the damage tolerance policy established in MIL-A-83444. This application has indicated that, with proper material selection and attention to design detail, the damage tolerance policy can be applied with minimum weight impact. This policy is now routinely applied at all major airframe companies.

For background on composites, see Composite Structures/Materials Certification Background under Requirement Lessons Learned for 3.10.1.2.

A.4.12 Damage tolerance.

Analysis and test shall be performed to verify that the airframe structure meets the damage tolerance requirements of 3.12 through 3.12.2.3. Beneficial effects of life enhancement

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processes must be approved by the procuring activity. The damage tolerance requirements shall be detailed and included in the structural criteria of 3.1.1.

VERIFICATION RATIONALE (A.4.12)

In order to maximize the probability of success in satisfying the detailed damage tolerance requirements, damage tolerance analyses and tests must be performed in all phases of the development of the airframe and not addressed after-the-fact. The detailed damage tolerance requirements and the associated verification requirements should be documented in the structural criteria for the airframe.

VERIFICATION GUIDANCE (A.4.12)

The specific tasks required to verify that the requirements of 3.12 through 3.12.2.3 are met are contained in the sections that follow.

VERIFICATION LESSONS LEARNED (A.4.12)

As demonstrated by both a fighter and a bomber development program, the key to achieving a damage tolerant structure is the selection of proper materials and paying attention to structural details. Because materials and detail structural concepts are selected very early in the development phase, damage tolerance requirements must be addressed as basic structural criteria.

A.3.12.1 Flaw sizes.

The airframe shall have adequate residual strength in the presence of flaws for specified periods of service usage. These flaws shall be assumed to exist initially in the structure as a result of the manufacturing process, normal usage and maintenance, and after an in-service inspection. The specific flaw size requirements are detailed in ________________________.

REQUIREMENT RATIONALE (A.3.12.1)

The establishment of realistic initial flaw size assumptions is necessary to insure that the airframe will have adequate residual strength capability throughout its service life.

REQUIREMENT GUIDANCE (A.3.12.1)

METALLIC STRUCTURES

Tables XXX, XXXI, and XXXII should be referenced in the blank and included in the specification. Additional guidance follows.

Initial flaw assumptions. Initial flaws are assumed to exist as a result of material and structure manufacturing and processing operations. Small imperfections equivalent to an .005 inch radius corner flaw resulting from these operations are assumed to exist in each hole of each element in the structure and provide the basis for the requirements in paragraphs d, e, and f, below. If the contractor has developed initial quality data on fastener holes (e.g., by fractographic studies, which provides a sound basis for determining equivalent initial flaw sizes), these data may be considered and serve as a basis for negotiating a size different than the specified .005 inch radius corner flaw. In addition, it is assumed that initial flaws of the size specified in paragraphs a and b can exist in any separate element of the structure. Each element of the structure should be surveyed to determine the most critical location for the assumed initial flaws considering such features as edges, fillets, holes, and other potentially high stressed areas. Only one initial flaw in the most critical hole and one initial flaw at a location other than a hole need be assumed to exist in any structural element. Interaction between these assumed initial flaws need not be considered. For multiple and adjacent

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elements; the initial flaws need not be situated at the same location (e.g., chordwise plan in wing structures, except for structural elements where fabrication and assembly operations are conducted such that flaws in two or more elements can exist at the same location). The most common example of such an operation is the assembly drilling of attachment holes. Except as noted in paragraphs d, e, and f, below, more than one source of common initial cracks need not be assumed along the crack growth path. Initial flaw sizes are specified in terms of specific flaw shapes, such as through the thickness or corner flaws at holes and semi-elliptical surface flaws or through the thickness flaws at locations other than holes.

Specified initial flaw sizes presume the inspection of 100 percent of all fracture critical regions of all structural components as required by the fracture control provisions of 3.12.1. This inspection should include as a minimum a close visual inspection of all holes and cutouts, and conventional ultrasonic, penetrant or magnetic particle inspection of the fracture critical regions. Where the use of automatic hole preparation and fastener installation equipment preclude close visual and dimensional inspection of 100 percent of the holes in the fracture critical regions of the structure, a plan to qualify and monitor hole preparation and fastener installation should be prepared and implemented by the contractor. Where special nondestructive inspection procedures have demonstrated a detection capability better than indicated by the flaw sizes specified in a, below, and the resulting smaller assumed flaw sizes are used in the design of the structure, these special inspection procedures must be used in the aircraft manufacturing quality control. In all situations indicated below, if development test data indicates that more severe flaw shapes than assumed are probable, worst case assumptions should prevail.

Smaller initial flaw sizes than those specified may be assumed subsequent to a demonstration, described in 4.12.2. Smaller initial flaw sizes may also be assumed if proof test inspection is used. In this case, the minimum assumed initial flaw size shall be the calculated critical size at the proof test stress level and temperature using acquisition activity approved upper bound of the material fracture toughness data.

a. Slow crack growth structure

At holes and cutouts, the assumed initial flaw is a .05 inch through the thickness flaw at one side of the hole when the material thickness is equal to or less than .05 inch. For material thicknesses greater than .05 inch, the assumed initial flaw is a .05 inch radius corner flaw at one side of the hole.

At locations other than holes, the assumed initial flaw is through the thickness flaw of .25 inch length when the material thickness is equal to or less than .125 inch. For material thicknesses greater than .125 inch, the assumed initial flaw is a semicircular surface flaw with a length (2c) equal to .25 inch and a depth (a) equal to .125 inch. Other possible surface flaw shapes with the same initial stress intensity factor (K) can be considered as appropriate; for example, corner flaws at edges of structural elements and longer and shallower surface flaws in plates which are subjected to high bending stresses. For welded structure, flaws should be assumed in both the weld and the heat affected zone in the parent material. For embedded defects, the initial flaw size assumption should be based on an assessment of the capability of the NDI procedure.

b. Fail safe structure (primary element)

At holes and cutouts the assumed initial flaw is a .05 inch through the thickness flaw at one side of the hole when the material thickness is equal to or less than .05 inch. For material thicknesses greater than .05 inch, the assumed initial flaw is a .05 inch radius corner flaw at one side of the hole.

At locations other than holes, the assumed initial flaw is a through the thickness flaw .25 inch in length when the material thickness is equal to or less than .125 inch. For material thicknesses

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greater than .125 inch, the assumed initial flaw is a semicircular surface flaw with a length (2c) equal to .25 inch and a depth (a) equal to .125 inch. Other possible surface flaw shapes with the same initial stress intensity factor (K) shall be considered as appropriate. For embedded defects, the initial flaw size assumption should be based on an assessment of the capability of the NDI procedure.

c. Fail safe multi-load path (adjacent structure)

The damage assumed to exist in the adjacent load path at the location of primary failure in fail safe multiple load path structure at the time of failure of a primary load path should be as follows:

(1) Multiple load path dependent structure. The same as specified in paragraph b, above, plus the amount of growth ($+\Delta a$) which occurs prior to primary load path failure.

(2) Multiple load path independent structure. The same as paragraph e.(2) plus the amount of growth ($+\Delta a$) which occurs prior to primary load path failure.

d. Fail safe crack arrest structure (adjacent structure)

For structure classified as fail safe crack arrest, the primary damage assumed to exist in the structure following arrest of a rapidly propagating crack depends upon the particular geometry. In conventional skin stringer (or frame) construction, this should be assumed as two panels (bays) of cracked skin plus the broken central stringer (or frame). Where tear straps are provided between stringers (or frames), this damage should be assumed as cracked skin between tear straps plus the broken central stringer (or frame). For other configurations, assume equivalent damage as mutually agreed upon by the contractor and the acquisition activity. The damage assumed to exist in the structure adjacent to the primary damage should be as specified in e.(2) or e.(3), below.

e. Continuing damage

Cyclic growth behavior of assumed initial flaws may be influenced by the particular geometry and arrangement of elements of the structure being qualified. The following assumptions of continuing crack growth should be considered for those cases where the primary crack terminates due to structural discontinuities or element failure.

(1) When the primary damage and growth originates in a fastener hole and terminates prior to member or element failure, continuing damage should be an .005 inch radius corner flaw plus the amount of growth (Δa) which occurs prior to primary element failure emanating from the diametrically opposite side of the fastener hole at which the initial flaw was assumed to exist.

(2) When the primary damage terminates due to a member or element failure, the continuing damage should be an .005 inch radius corner flaw in the most critical location of the remaining element or remaining structure or a surface flaw having 2c = .02 inch and a = .01 inch, where, a is measured in the direction of crack growth plus the amount of growth (Δa) which occurs prior to element failure.

(3) When the crack growth from the assumed initial flaw enters into and terminates at a fastener hole, continuing damage should be an .005 inch radius corner flaw + Δ a emanating from the diametrically opposite side of the fastener hole at which the primary damage initiated or terminated, whichever is more critical.

f. In-service inspection flaw assumptions

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The smallest damage which is presumed to exist in the structure after completion of a depot or base level inspection should be as follows unless specific NDI procedures have been developed and the detection capability quantified.

(1) Where NDI techniques such as penetrant, magnetic particle, eddy current, or ultrasonics are applied without component or fastener removal, the minimum assumed flaw size at holes and cutouts should be a through the thickness crack emanating from one side of the hole having a 0.25 inch uncovered length when the material thickness is equal to or less than 0.25 inch. For material thicknesses greater than 0.25 inch, the assumed initial flaw should be a quarter-circular corner crack emanating from one side of the hole having a 0.25 inch uncovered length. The minimum assumed flaw size at locations other than holes should be a through the thickness crack of length 0.50 inch when the material thickness is equal to or less than 0.25 inch. For material thicknesses greater than 0.25 inch, the assumed initial flaw should be a semicircular surface flaw with length (2c) equal to 0.50 inch and depth (a) equal to 0.25 inch. Other possible surface flaw shapes with the same initial stress intensity factor (K) can be considered as appropriate such as corner flaws at edges of structural members and longer and shallower surface flaws in plates which are subjected to high bending stresses. While X-ray inspection may be used to supplement one or more of the other NDI techniques, it by itself, cannot be considered capable of reliably detecting tight subcritical cracks.

(2) If the component is to be removed from the aircraft and completely inspected with an NDI technique, the minimum assumed damage is that detectable flaw that the NDI technique can demonstrate with an 90 percent probability and a 95 percent confidence level.

(3) Where accessibility allows close visual inspection (using visual aid as necessary), an opening through the thickness crack having at least two inches of uncovered length should be the minimum assumed damage size.

(4) Where accessibility, paint, sealant, or other factors preclude close visual inspection or the use of NDI techniques such as described in (2) above, slow crack growth structure should be considered to be noninspectable and fail safe structure should be considered to be inspectable only for major damage such as a load path failure or arrested unstable crack growth.

g. Fastener policy for damage tolerance

To maximize safety of flight and to minimize the impact of potential manufacturing errors, it should be a goal to achieve compliance with the damage tolerance requirements of this specification without considering the beneficial effects of specific joint design and assembly procedures such as interference fasteners, cold expanded holes, or joint clamp-up. In general, this goal should be considered as a policy but exceptions can be considered on an individual basis. The limits of the beneficial effects to be used in design should be no greater than the benefit derived by assuming a .005 inch radius corner flaw at one side of an as-manufactured, non-expanded hole containing a neat fit fastener in a non-clamped-up joint. A situation that might be considered an exception would be one involving a localized area of the structure involving a small number of fasteners. In any exception, the burden of proof of compliance by analysis, inspection, and test is the responsibility of the contractor.

SPECIAL COMPONENTS

In lieu of more specific data, the flaw size assumptions listed herein are applicable. Generally, individual components can be inspected to a higher level than a large general area and smaller initial flaw size assumptions might be developed.

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COMPOSITE STRUCTURES

The composite structure must also be designed to be easily repairable for expected in-service damage. Further, the design usage must be carefully identified. The design missions must be adequately defined such that the potentially damaging high load cases are properly represented.

In addition to the threats described above, the safety of flight structure must be designed to meet other damage threats. These threats are those associated with manufacturing and in-service damage from adverse usage and battle damage. The initial flaw/damage assumptions are described in table IX for manufacturing initial flaws and in-service damage. The 100 ft-lb of energy required to cause a dent 0.10 inch deep may be reduced if the structure is not exposed to the external impact or maintenance damage threats and the part is thoroughly inspected before closing up. To qualify the structure under this reduced impact energy criteria, the proposed impact energy of ________ shall be approved by the procuring agency and the damage resulting from the impact which will grow to critical sizes in two lifetimes of spectrum loadings shall be detectable by industry standards or special demonstrated NDI techniques. The design development tests to demonstrate that the structure can tolerate these defects for its design life without in-service inspections shall utilize the unclipped upper bound spectrum loading and the environmental conditioning developed for the durability tests. These two lifetime tests must show with high confidence that the flawed structure meets the residual strength requirements in table X. These residual strength requirements are the same for the metallic structures except the P_{xx} is not limited to 1.2 times the maximum load in one lifetime. To obtain the desired high confidence in the composite components it is necessary to show that either the growth of the initial flaws arrests and is insignificant, or the damage/flaw will not grow to critical size in two design lifetimes by analysis and the analysis methods could be verified by component testing. As for the durability tests there shall be a program to assess the sensitivity to changes in the baseline design usage spectrum.

OTHER MATERIAL SYSTEMS

While the specifics of the above guidance apply to metallic and composite structures, any structural material system and design approach must comply with the intent of the requirement. Initial flaw size assumptions should be established after an assessment of the design, manufacturing procedures, and inspection method capabilities. Specifically, for organic matrix composites, flaws which are induced in service (foreign object damage, handling damage, etc.) must be considered when the structure is categorized, the degree of inspectability is defined, and the initial flaw size assumptions are established. The size of damage of concern from these low energy impact sources is that size which would not be readily detectable in a routine visual inspection. The impact energy level to be assumed in design for each area of the structure should be that level which produces barely perceptible front face damage in the structure. Because the amount of energy necessary to achieve this level of damage is usually a function of the thickness of the structure, an upper bound energy level cutoff should be established for various zones on the structure dependent on the possible sources of damage. In general, it will be necessary for the contractor to conduct this initial flaw size assessment as part of the contract when the design, manufacturing methods, and inspection techniques are sufficiently defined.

REQUIREMENT LESSONS LEARNED (A.3.12.1)

Two different approaches have been employed in the past to establish initial flaw size assumptions for use in design. In a fighter development, MIL-A-83444 flaw sizes were used in general with exceptions taken at specific locations with NDI demonstrated values. In a bomber development, an extensive NDI capability assessment was performed and smaller than spec

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size initial flaws were assumed. While both approaches were successful, they both have their advantages and disadvantages, and the technique to be employed should be evaluated on a system by system basis.

A.4.12.1 Flaw sizes.

Production inspections shall be performed on 100 percent of all fracture critical regions of all airframes and related structural components. These inspections shall include, as a minimum, close visual inspections of all holes and cutouts and conventional ultrasonic, penetrant, or magnetic particle inspection of the remainder of the fracture critical region. When automatic hole preparation equipment is used, acquisition activity approved demonstration to quality and statistically monitor hole preparation and fastener installation may be established and implemented to satisfy this requirement.

a. Special nondestructive inspections.

(1) Where initial flaw assumptions for safety of flight structures are less than those of 3.12.1, a nondestructive inspection demonstration shall be performed. This demonstration shall verify that all flaws equal to or greater than the assumed flaw size will be detected with a statistical confidence of ______________.

(2) The demonstration shall be conducted on each selected inspection procedure using production conditions, equipment, and personnel. The defective hardware used in the demonstration shall contain actual flaws and cracks which simulate the case of tight fabrication flaws. Subsequent to successful completion of the demonstration, specifications on these inspection techniques shall become the manufacturing inspection requirements and may not be changed without requalification and acquisition activity approval.

b. Inspection proof tests. Component, assembly, or complete airframe inspection proof tests of every airframe shall be performed whenever the special nondestructive inspections of 4.12.1 cannot be validated and initial flaw assumptions for damage tolerant structures are less than those of 3.12.1. The purpose of this testing shall be to define maximum possible initial flaw sizes or other damage in slow crack growth structure.

c. In-service inspections. Demonstration test articles shall be inspected to show that any required in-service inspection can be conducted on the airframe. The airframe shall be inspected in accordance with the designated inspectability levels of 3.12 during the course of the testing of 4.11.1.2.2 and 4.12.2.b.

VERIFICATION RATIONALE (A.4.12.1)

The key element in assuring that the production airframes will satisfy damage tolerance criteria is to insure that the quality of the structure meets established minimum acceptance levels. This can only be accomplished by subjecting each critical structural location to a thorough inspection during fabrication.

VERIFICATION GUIDANCE (A.4.12.1)

All fracture critical regions need to be identified. The required inspections need to comply with the requirements of MIL-I-6870. The types of inspections to be performed must be consistent with the initial flaw size assumptions established for the particular area of interest. A formal procedure should also be established to document and provide disposition criteria for anomalies found during the inspections.

VERIFICATION LESSONS LEARNED (A.4.12.1)

VERIFICATION RATIONALE (A.4.12.1.a)

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A demonstration is required to validate the reliability of special inspection techniques.

VERIFICATION GUIDANCE (A.4.12.1.a)

A flaw size smaller than the design flaw size must have a probability of detection of 90 percent. This capability must be verified with a 95 percent confidence level by conducting a statistically valid demonstration. This special inspection provision in the specification should not be employed to cover basic structural deficiencies in new structures. It is recommended that thorough consideration be given to the following factors before a structural component is permitted to be qualified and certified using special inspection techniques:

a. As a minimum, the component should satisfy all requirements in the specification with the smaller initial flaw size assumption.

b. The component should be depot or base level inspectable in case the need for in-service inspection should arise from a change in usage or operational environment.

c. A life cycle cost advantage to the Air Force should be demonstrated.

VERIFICATION LESSONS LEARNED (A.4.12.1.a)

Special nondestructive inspection demonstrations have been successfully completed, for example, in a bomber design, dye penetrant inspections were qualified to smaller flaw sizes.

VERIFICATION RATIONALE (A.4.12.1.b)

Proof-testing can be a highly reliable inspection technique that can be used where standard inspection methods cannot be employed, provided that the full impact of the test on the structure can be assessed.

VERIFICATION GUIDANCE (A.4.12.1.b)

A decision to employ proof-testing must take the following factors into consideration:

a. The loading that is applied must accurately simulate the peak stresses and stress distributions in the area being evaluated.

b. The effects of the proof-test loading on other areas of the structure must be thoroughly evaluated.

c. Local plasticity effects must be taken into account in determining the maximum possible initial flaw size after test and in determining subsequent flaw growth.

VERIFICATION LESSONS LEARNED (A.4.12.1.b)

Production type proof-testing has been successfully employed on a swing wing fighter wing pivot fitting, a bomber wing, and a fighter horizontal tail. Proof-testing of a fighter's speed brake was less than successful because the proof-test loading did not accurately load the portion of the structure which eventually experienced problems in service.

VERIFICATION RATIONALE (A.4.12.1.c)

Demonstration of the inspection techniques and procedures on actual hardware is required to validate the proposed procedures.

VERIFICATION GUIDANCE (A.4.12.1.c)

Inspections of the full scale test articles should be performed using the techniques and procedures planned for in-service use. Flight test articles can also be employed.

VERIFICATION LESSONS LEARNED (A.4.12.1.c)

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Numerous cases in the past have occurred where inspections were called out for areas that were difficult to inspect because of accessibility limitations or other considerations that were overlooked. Demonstration of the inspection procedures on the full-scale test airframe usually identifies these problems, but interferences from other factors, such as equipment and plumbing not usually installed on the test airframe, should be taken into account.

A.3.12.2 Residual strength and damage growth limits.

The minimum required residual strength is specified in terms of the internal member load which the airframe must be able to sustain with damage present for the specified period of unrepaired service usage. The magnitude of this load shall be based on the overall degree of inspectability of the structure and is intended to represent the maximum load the internal member might encounter during a specified inspection interval or during a life time for noninspectable structure. This load (P_{XX}) is defined as a function of the specific degree of inspectability in ________________________.

REQUIREMENT RATIONALE (A.3.12.2)

Residual strength requirements must be established to insure the safety of flight of the structure at every point in time during its service life.

REQUIREMENT GUIDANCE (A.3.12.2)

This requirement applies to all safety of flight structure including doors, and door and ramp mechanisms (see 3.3.1 and 3.3.2), if applicable. Table X is to be referenced in the blank and included in the specification.

REQUIREMENT LESSONS LEARNED (A.3.12.2)

The selection of a value for P_{XX} has varying degrees of significance depending on the crack growth rate characteristics of the material, the structural design details, the potential usage variations, and the actual degree of inspectability. All cases which result in P_{XX} being less than design limit load should be carefully evaluated on an individual basis to insure that no undue risk is being incorporated.

a. Airframe loading spectrum. The airframe loading spectrum shall reflect required missions wherein the mission mix and the loads in each mission segment represent service usage. The required residual strength in terms of a maximum load must be greater than the maximum load expected during a given interval between inspections.

REQUIREMENT RATIONALE (A.3.12.2.a)

To account for the fact that any individual aircraft may encounter loads considerably in excess of the average during its life, the required residual strength must be equal to or larger than the maximum load expected during a given interval between inspections.

REQUIREMENT GUIDANCE (A.3.12.2.a)

This is accomplished by magnifying the inspection interval. For example, the P_{XX} load for ground evident damage is the maximum load that could be expected once in 100 flights (see table X).

REQUIREMENT LESSONS LEARNED (A.3.12.2.a)

b. Fail-safe structure. For fail-safe structure, a minimum load (P_{yy}) shall be sustained by the remaining structure at the instant of load path failure of the primary member. This load, defined in 3.12.2, shall be sustained by the secondary member at any time during the inspection interval defined in 3.12.2. The magnitude of this load shall be the product

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of a dynamic factor and the load defined in 3.12.2 or the product of a dynamic factor and the internal member load at design limit load whichever is greater. The dynamic factor shall be ___________________.

REQUIREMENT RATIONALE (A.3.12.2.b)

This paragraph establishes the requirement for fail safe structure to sustain a minimum load, P_{YY}, the instant of load path failure.

REQUIREMENT GUIDANCE (A.3.12.2.b)

In lieu of test or analytical data to the contrary, a dynamic factor (D.F.) of 1.15 is to be applied to the redistributed incremental load. This dynamic factor should be verified by test for non-metallic structures.

REQUIREMENT LESSONS LEARNED (A.3.12.2.b)

c. Safety of flight structure. All safety of flight structure shall maintain the required residual strength in the presence of damage for specific period of unrepaired service usage as a function of design concept and degree of inspectability. Periods of unrepaired service usage shall be as specified below. For pressurized portions of the structure, the minimum required residual strength shall be based on a factor times the most negative and the most positive pressure differential attainable with normal cabin pressure system operation including expected external aerodynamic pressures and the effects of adverse tolerances combined with the appropriate required residual strength flight and landing loads.

(1) Periods of unrepaired service usage are shown in _______________.

(2) The pressure differential factor is __________________.

REQUIREMENT RATIONALE (A.3.12.2.c)

In order to insure that the structure's residual strength is not degraded, with the presence of cracking or a failed member, the structure must withstand a period of service usage longer than the planned inspection interval.

REQUIREMENT GUIDANCE (A.3.12.2.c)

a. Table XXXIII is to be referenced in the blank and included in the specification.

b. The pressure differential factor should be 1.15 unless a different factor is substantiated by analysis or test.

REQUIREMENT LESSONS LEARNED (A.3.12.2.c)

Because of variations in material properties, manufacturing processes, and usage, a margin on the inspection interval is required to minimize risk. Inspection should be conducted at one-half of the calculated minimum period of safe unrepaired service usage (i.e., the safety limit) for situations where structural disassembly is required for a number of reasons:

a. Inspection reliability is improved because two inspections are performed at or prior to the safety limit.

b. Some flexibility can be allowed when the inspection intervals from various locations in the structure are combined into a practical maintenance plan.

c. The possibility of damaging the structure during disassembly is kept to a minimum.

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A.3.12.2.1 Slow crack growth structure.

The initial damage as defined in 3.12.1, which can be presumed to exist in the structure as manufactured, shall not grow to a critical size and cause failure of the structure due to the application of the maximum internal member load in two lifetimes of the service life and usage of 3.2.14 as modified by 3.12.2.a.

REQUIREMENT RATIONALE (A.3.12.2.1)

In order to insure the safety of flight of the structure, it must be able to sustain the planned service usage for a period that is longer than required to account for variability in material properties, manufacturing quality, and inspection reliability.

REQUIREMENT GUIDANCE (A.3.12.2.1)

For metallic structure, the minimum acceptable period of unrepaired service usage for slow crack growth structure is two service usage lifetimes, i.e., the time for a flaw to propagate to failure from some initial damage must be in excess of two service usage lifetimes. For non-metallic structure, the minimum acceptable period of unrepaired service usage is also two service usage lifetimes. To achieve this requirement, the following criteria should be satisfied for non-metallic structure:

a. Manufacturing induced flaws: No growth or positive crack arrestment in two service usage lifetimes from the flaw sizes established in 3.12.1.

b. Service induced damage: No growth to failure in two service usage lifetimes from the flaw sizes established in 3.12.1.

REQUIREMENT LESSONS LEARNED (A.3.12.2.1)

A.3.12.2.2 Fail-safe multiple load path structure.

The degrees of inspectability for fail-safe multiple load path structure are in-flight evident, ground evident, walk-around, special visual, and depot/base level inspectable. The frequency of inspection for each of these inspectability levels shall be as below.

a. Initial inspection interval. The initial inspection interval and residual strength requirements are a function of the degree of inspectability of the primary element and shall be as shown in ____________.

b. Subsequent inspection intervals. The subsequent inspection intervals and residual strength requirements are also based on the degree of inspectability of the primary element and shall be as shown in ____________.

REQUIREMENT RATIONALE (A.3.12.2.2)

Fail-safe structure must be designed to withstand a specified period of service usage after a primary load path failure. This period of usage depends on the type and frequency of the inspections for the particular structure.

REQUIREMENT GUIDANCE (A.3.12.2.2)

Specific guidance for various levels of inspectability is contained in the subsequent subparagraph. The definition of the correct level of inspectability for each structural element is extremely important and it must take into consideration such factors as accessibility, the influence of paint or other coatings, and the loading on the structure when the inspection is performed. Doors and door and ramp mechanisms should be qualified under this category (see 3.3.1 and 3.3.2) when applicable.

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REQUIREMENT LESSONS LEARNED (A.3.12.2.2)

There are currently no aircraft in the Air Force inventory which have been designed and qualified as fail-safe multiple load path structure under Air Force criteria. However, selected components of three aircraft are being managed as fail-safe structure as a result of durability and damage tolerance assessments.

REQUIREMENT RATIONALE (A.3.12.2.2.a)

Fail-safe structure must be designed to withstand a specified period of service usage after a primary load path failure. An initial inspection interval must be established to insure detection of any premature primary element failure.

REQUIREMENT GUIDANCE (A.3.12.2.2.a)

Reference table XXXIII and figures 28 and 29 in the blank and include the table and figures in the specification. Each primary load carrying member must be considered in turn as the primary element. The initial inspection interval should not be greater than one half of the time to primary load path failure from an initial flaw as specified in 3.12.1 for primary elements, plus one half of the remaining time to failure of adjacent structure from the flaw size specified in 3.12.1 for adjacent load paths at the time of primary element failure. Residual strength requirements are as indicated in 3.12.2.

REQUIREMENT LESSONS LEARNED (A.3.12.2.2.a)

REQUIREMENT RATIONALE (A.3.12.2.2.b)

Fail-safe structure must be designed to withstand a specified period of service usage after a primary load path failure. This period of usage depends on the degree of inspectability of the particular structure.

REQUIREMENT GUIDANCE (A.3.12.2.2.b)

Reference table XXXIV and figure 30 in the blank and include the table and figure in the specification.

REQUIREMENT LESSONS LEARNED (A.3.12.2.2.b)

A.3.12.2.3 Fail-safe crack arrest structure.

The degrees of inspectability applicable to fail-safe crack arrest structure are the same as for fail-safe multiple load path structures defined in 3.12.2.2.

a. Initial inspection interval. The initial inspection interval and residual strength requirements are dependent on the particular geometry and the degree of inspectability and shall be as shown in _____________.

b. Subsequent inspection intervals. The subsequent inspection intervals and residual strength requirements are also based on the degree of inspectability of the primary damage and shall be as shown in ________________.

REQUIREMENT RATIONALE (A.3.12.2.3)

Fail-safe crack arrest structure must be able to withstand a specified period of service usage after a primary load path failure. This period of usage depends on the type and frequency of the inspections for the particular structure.

REQUIREMENT GUIDANCE (A.3.12.2.3)

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Specific guidance for the various levels of inspectability is contained in subsequent subparagraphs.

REQUIREMENT LESSONS LEARNED (A.3.12.2.3)

There are currently no aircraft in the Air Force inventory which have been qualified as fail-safe crack arrest structure under Air Force criteria.

REQUIREMENT RATIONALE (A.3.12.2.3.a)

Fail-safe crack arrest structure must be able to withstand a specified period of service usage after a primary load path failure. This period of usage depends on the type and frequency of the inspections for the particular structure.

REQUIREMENT GUIDANCE (A.3.12.2.3.a)

Reference table XXXIII and figure 31 in the blank and include the table and figure in the specification. The type and extent of the primary damage is a function of the particular geometry and is defined in 3.12.1 under initial flaw sizes for fail-safe crack arrest structures. Residual strength requirements are as indicated in 3.12.2.

The initial inspection interval should not be greater than one half of the time to primary damage (see below) plus one half of the remaining time to failure of the adjacent structure from the flaw size specified in 3.12.1 for adjacent structure at the time of primary damage in fail-safe crack arrest structure. The time to primary damage is determined by assuming an initial flow (the same flow size as is specified in 3.12.1 for the primary element in fail-safe structure) in the critical element in the primary damage area. The individual flaws in other elements of the primary damage area with the sizes specified in 3.12.1 for fail-safe multiple load path adjacent structure are allowed to propagate to element failure until all elements of the primary damage area have failed. Load redistribution effects as each element fails must be taken into account in the growth of the flaws in the remaining elements.

REQUIREMENT LESSONS LEARNED (A.3.12.2.3.a)

REQUIREMENT RATIONALE (A.3.12.2.3.b)

Fail-safe crack arrest structure must be able to withstand a specified period of service usage after a primary load path failure. This period of usage depends on the type and frequency of the inspections for the particular structure.

REQUIREMENT GUIDANCE (A.3.12.2.3.b)

Reference table XXXIV and figure 32 in the blank and include the table and figure in the specification.

REQUIREMENT LESSONS LEARNED (A.3.12.2.3.b)

A.4.12.2 Residual strength and damage growth limits.

Analyses and tests shall be conducted to verify that the airframe meets the damage tolerance requirements of 3.12.

a. Analyses. Damage tolerance analyses consisting of crack growth and residual strength analyses shall be performed. The analyses shall assume the presence of flaws placed in the most unfavorable location and orientation with respect to the applied stresses and material properties. The crack growth analyses shall predict the growth behavior of these flaws in the chemical, thermal, and sustained and cyclic stress environments to which that portion of the component shall be subjected in service. The flaw sizes to be used in the

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analysis are those defined in 3.12.1. The flight-by-flight stress spectra and chemical and thermal environment spectra shall be developed in accordance with 4.2.15 and 3.12.2.a. Spectrum interaction effects, such as variable loading and environment, shall be accounted for. The analyses shall demonstrate that cracks growing from the flaw sizes of 3.12.1 will not result in sustained crack growth under the maximum steady flight and ground loads of the usage of 3.2.14 as modified by 3.2.12.a.

b. Tests. Development (___) and full scale (___) damage tolerance tests are required to demonstrate that the airframe structure meets the requirements of 3.12. The material properties derived from development tests shall be consistent and congruent with those properties of the same material, in the same component, used by the other structures disciplines. See 3.2.19.1.

VERIFICATION RATIONALE (A.4.12.2)

A comprehensive analysis and test effort is required to validate the damage tolerance capability of the airframe.

VERIFICATION GUIDANCE (A.4.12.2)

The verification that the requirements of 3.12.1 have been satisfied requires an extensive evaluation and interpretation of design analysis, development testing, full-scale testing, and post test analysis results. Because of analysis limitations and testing complexity, an individual analysis or test requirement cannot be accurately evaluated without supporting information from the other requirements. Specific guidance concerning the required analyses and testing is contained in the following subparagraphs. Where analytical capability is invalidated or does not exist, the development testing must be expanded to compensate for this deficiency.

VERIFICATION LESSONS LEARNED (A.4.12.2)

Both a fighter and a transport wing design have been validated by conducting analysis and test verification of the damage tolerance requirements. Lessons learned from these efforts are contained in the following subparagraphs.

VERIFICATION RATIONALE (A.4.12.2.a)

The development of a validated analysis methodology for each fracture critical component of the structure is of primary importance. The ability to predict the crack growth behavior of a flaw in any component over the entire range of expected crack sizes and shapes, possible usage variations, and operating environments is critical to the management of fleet airframe resources throughout the service life of the air vehicle.

VERIFICATION GUIDANCE (A.4.12.2.a)

Crack growth and residual strength analyses should be conducted for each critical location of each fracture critical component to demonstrate compliance with the requirements under the indicated assumptions. The validity of the analytical methods should be demonstrated by correlation with the testing indicated in paragraph b. below. The analysis methods should be updated, corrected, or modified as necessary as test results become available to obtain the best predictive capability possible.

The test data and analysis should be thoroughly studied to identify any trends in the correlation with regard to such factors as initial flaw size, shape, structural geometry, or environment which may isolate analysis deficiencies. An analysis method should not be considered acceptable based on the fact that it has been demonstrated to be overly conservative in all test correlations. This can have serious repercussions if under some future usage variation the method predicts an unrealistically short life.

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As for metal structures, the damage tolerance analyses for composites are inexorably linked to the design development tests. For support of these analyses it is recommended that the design development testing consist of "building blocks" ranging from coupons to elements, to subcomponents, and finally to components.

VERIFICATION LESSONS LEARNED (A.4.12.2.a)

VERIFICATION RATIONALE (A.4.12.2.b)

Extensive development and full-scale damage tolerance tests are required to verify the analytical predictions and to support force management of the air vehicles.

VERIFICATION GUIDANCE (A.4.12.2.b)

Indicate the testing that is applicable. Test requirements should be defined according to the following guidance:

Damage tolerance development tests: Development testing should be conducted to provide data for the following areas:

a. Material properties
b. Analytical procedure verification of crack growth rates and residual strength
c. Stress level effects
d. Spectrum effects
e. Early validation of the damage tolerance critical components

In addition, data should be generated to validate the methods to be used in introducing artificial damage (sharp fatigue cracks) in the full-scale test airframe. If early testing indicates that the design spectrum does not adequately mark the fracture surfaces for use in fractographic analysis, a scheme to artificially mark the fracture surfaces at periodic intervals should be developed. Development testing should consist of a progression from basic material property tests through a series of test specimens with increasing levels of geometry and loading complexity. These tests are intended to provide more information than just indicating whether a given structural detail will likely meet the minimum structural requirements. In order to verify an analytical failure prediction, both the predicted time to failure and the predicted failure mode must be verified. This implies that at least some of the development tests, with a sufficient level of loading and geometry complexity which accurately simulate the full scale structure, must be tested to failure. The same applies to testing to determine stress level, spectrum, and environmental sensitivities. Both the time to failure and the failure modes must be verified.

The damage tolerance analyses for composites are linked to the development tests. In support of these analyses it is recommended that the development testing consist of "building blocks" ranging from coupons to elements, to subcomponents, and finally to components. These building block tests must include room temperature dry laminates. Also, if the effects of the environment are significant, then environmentally conditioned tests must be performed at each level in the building block process. The test articles are to be strain gaged adequately to obtain data on potentially critical locations and for correlation with the full scale static test, and in addition, the test program is to be performed so that environmentally induced failure modes (if any) are discovered. The design development tests are complete when the failure modes have been identified, the critical failure modes in the component tests are judged to be not significantly affected by the non-representative portion of the test structure and the structural sizing is judged to be adequate to meet the design requirements. For static test components,

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this judgment is based on adjusting the failure loads to the "B" basis environmentally conditioned allowable.

Damage tolerance tests: A complete airframe or approved alternatives should be damage tolerance tested to demonstrate compliance with the requirements. See 4.10.5.2.1 through 4.10.5.2.4 for additional guidance for full-scale testing.

a. Test article. The test airframe or components should be as structurally identical to the operational airframe as production practicalities will permit. Any differences, including material or manufacturing process changes, should be assessed for impact. The assessment should include additional component testing if the changes are significant. The test articles should include artificially induced damage by the techniques developed in development testing. The sharp fatigue cracks introduced should be of the appropriate size and shape consistent with the initial flaw size assumptions for the component. It is recommended that the full-scale durability test article be employed for this testing at the completion of the required durability testing (see 4.11.1.2.2.e). This approach has several advantages. First, any naturally developed fatigue cracks will be present, eliminating the need to artificially induce damage. Second, additional durability information is developed. Third, a cost savings can be realized by not having to fabricate a second test article. The amount of artificial damage that is introduced into the test article is a function of the number of identified fracture critical locations, the number of naturally developed cracks if the durability article is used, and practical limitations caused by the particular structure. Extensive tear-down of a structure to introduce damage at an isolated location is usually not warranted unless the analysis and development testing indicate that proper internal member loading can only be simulated in the full-scale article.

b. Test requirements

(1) The airframe or component damage tolerance tests should be performed in accordance with the guidance provided below.

(2) If the crack growth rates demonstrated during the full-scale testing are different than expected from analysis or development testing, additional analysis and testing should be conducted to substantiate the full-scale test results.

c. Test spectrum.

(1) A flight-by-flight test spectrum should be derived from the service loads and chemical and thermal environment spectra of 3.2. The effects of chemical and thermal environmental spectra should be thoroughly evaluated during the development testing, and these spectra should be included in the full-scale testing only if the development testing results indicate that it is necessary.

(2) High and low load truncation, elimination, or substitution of load cycles should be substantiated by development testing.

d. Inspections. Major inspections should be performed as an integral part of the damage tolerance testing. Proposed in-service inspection techniques will be evaluated during the tests. Surface crack length measurements should be recorded during the tests. Evaluate surface crack length . The end-of-test inspection should include a structural teardown, a removal of cracked areas, and fractographic analysis of all significant fracture surfaces.

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e. Duration. The duration of the tests should be sufficient to verify crack growth rate predictions. The test may need to run for one lifetime, but sufficient information might be derived in a shorter period.

f. Composite structures. Full scale testing is an essential element of ASIP. There is normally a full scale durability and damage tolerance test in the development of a weapon system, however, these tests are generally for the verification of the metal structure. In those cases where the metallic structure durability and damage tolerance tests capability can be confidently established in the design development tests, then the full scale durability and damage tolerance tests may not be required. For example, a structure that is primarily composite, but contains a limited number of metallic joints, may fall into this category. Normally, the durability and damage tolerance capability of the composite structure can be verified by the design development tests.

VERIFICATION LESSONS LEARNED (4.12.2.b)

A.3.13 Durability and damage tolerance control.

A durability and damage tolerance control process shall be developed and maintained to ensure that maintenance and fatigue/fracture critical parts meet the requirements of 3.11 and 3.12.

REQUIREMENT RATIONALE (A.3.13)

The process shall identify and define all of the tasks necessary to ensure compliance with the durability and damage tolerance requirement.

REQUIREMENT GUIDANCE (A.3.13)

The disciplines of fracture mechanics, fatigue, materials selection and processes, environmental protection, corrosion prevention and control, design, manufacturing, quality control, and nondestructive inspection are involved in damage tolerance and durability control. The MIL-STD-1568 or equivalent documents should be used as a guide in the development of corrosion prevention and control process.

The durability and damage tolerancecontrol process should include as a minimum the following tasks:

a. A disciplined procedure for durability design should be implemented to minimize the possibility of incorporating adverse residual stresses, local design details, materials, processing, and fabrication practices into the problems (i.e., to find these problems which otherwise have historically been found during durability testing or early in service usage).

b. Basic data (i.e., initial quality distribution, fatigue allowables, K_{IC}, K_C, K_{ISCC}, da/dn, etc.) utilized in the initial trade studies and the final design and analyses should be obtained from existing sources or developed as part of the contract.

c. A criteria for identifying and tracing maintenance critical parts should be established by the contractor and should require approval by the procuring agency. It is envisioned that maintenance critical parts will be expensive, non-economical-to-replace parts. A maintenance critical parts list should be established by the contractor and should be kept current as the design of the airframe progresses.

d. A criteria for identifying and tracing fatigue/fracture critical parts should be established by the contractor and should require approval by the procuring agency. It is envisioned that fatigue/fracture critical parts will be expensive or safety of flight structural parts. A fatigue/fracture critical parts list should be established by the contractor and should be kept current as the design of the airframe progresses.

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e. Design drawings for the maintenance critical parts and fatigue/fracture critical parts should identify critical locations, special processing (e.g., shot peenings), and inspection requirements.

f. Material procurement and manufacturing process specifications should be developed and updated as necessary to ensure that initial quality and fracture toughness properties of the critical parts exceed the design value.

g. Experimental determination sufficient to estimate initial quality by microscopic or fractographic examination should be required for those structural areas where cracks occur during full scale durability testing. The findings should be used in the full scale test data interpretation and evaluation task as specified in 4.11.1.2.2.c and, as appropriate, in the development of the force structural maintenance plan as specified in 4.14.

h. Durability analyses, damage tolerance analyses, development testing, and full scale testing should be performed in accordance with this specification.

i. Complete nondestructive inspection requirements, process control requirements, and quality control requirements for maintenance, fatigue/fracture critical parts should be established by the contractor and should require approval by the procuring agency. MIL-I-6870 should be used as a guide in the development of Nondestructive Inspection procedures. This task should include the proposed plan for certifying and monitoring subcontractor, vendor, and supplier controls.

j. The durability and damage tolerance control process should include any special nondestructive inspection demonstration programs conducted in accordance with the requirements of this specification.

k. Traceability requirements should be defined and imposed by the contractor on those fatigue and fracture critical parts that receive prime contractor or subcontractor in-house processing and fabrication operations which could degrade the design material properties.

l. For all fracture critical parts that are designed for a degree of inspectability other than in-service non-inspectable, the contractor should define the necessary inspection procedures for field use for each appropriate degree of inspectability as specified in the specification.

The durability and damage tolerance control process is similar to what is normally accomplished in most companies during system development and manufacturing. It does, however, represent a significantly more rigorous application of controls and a directed interdisciplinary effort among the company's functional organizations. To accomplish this task, a Durability and Damage Tolerance Control Board or Team should be established to oversee the control process. The control process should establish the criteria for critical part selection and the control of the critical parts. The selection of critical parts starts as system design requirements are translated into a design and analyses are accomplished. Trade studies are performed to determine the most cost effective, lowest weight design. After a design is finalized, durability, fatigue/fracture critical parts are chosen, according to a set of predetermined criteria. Additional design trade studies may result in parts being added to or deleted from the critical parts list. Critical parts can also be selected by engineering judgment. These parts, although not critical according to predetermined criteria, may be deemed critical because of economic consequences of failure (e.g., expensive to repair or replace), or by the aircraft not being mission capable, etc. Those parts that do not make the list are subject to normal controls.

REQUIREMENT LESSONS LEARNED (A.3.13)

Without proper durability and damage tolerance control process, the structural integrity cannot be maintained and the cost/weight within the performance requirements cannot be achieved.

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The control process should be coordinated with all the disciplines and the parts selected for control should be passed through detailed critical parts selection process. The same control process should be implemented in the supply vendors.

A.4.13 Durability and damage tolerance control.

The durability and damage tolerance control process shall be properly documented and implemented to ensure that maintenance and fatigue/fracture critical parts meet the requirements 3.11 and 3.12.

VERIFICATION RATIONALE (A.4.13)

The process identifies the management approach to ensure the contractor's coordinated interdisciplinary functions to design and produce a fatigue resistant and damage tolerant aircraft.

VERIFICATION GUIDANCE (A.4.13)

Durability and damage tolerance process control needs to be established to identify the maintenance, fatigue/fracture critical parts selection, and critical parts control. The control of critical parts is administered by the Durability and Damage Tolerance Control Board. The board is comprised of a broad range of people that represent different functional areas within the company - engineering, manufacturing, quality assurance, etc. The board is responsible for establishing and overseeing the administration of the specific controls that will be applied to the critical parts.

VERIFICATION LESSONS LEARNED (A.4.13)

Durability and Damage Tolerance Controls have been developed and used successfully on recent development programs. Contractors have found durability and damage tolerance control to be a sound and reasonable approach to ensuring structural integrity. The number of critical parts selected should be adequate without overloading the manufacturing process.

A.3.14 Sensitivity analysis.

In service airframe structural life and life cycle cost shall not be significantly degraded by small variations in weight, maneuverability, usage, and _______.

REQUIREMENT RATIONALE (A.3.14)

In-service airframe structural life can be significantly degraded by small variations in design parameters such as weight, maneuverability, etc. A sensitivity analysis is performed to evaluate the effects of variations of these design parameters on airframe structural life and its impact on life cycle cost.

REQUIREMENT GUIDANCE (A.3.14)

The sensitivity analysis task encompasses those efforts required to apply the existing theoretical, experimental, applied research, and operational experience to specific criteria for materials selection and structural design for the airplane. The objective is to ensure that the appropriate criteria and planned usage are applied to an airplane design so that the specific operational requirements will be met. This task begins as early as possible in the conceptual phase and is finalized in subsequent phases of the airplane life cycle. The analysis should document the impact of variations of design parameters such as: a 10% increase in mission weight, a 5% increase in spectrum severity, etc on structural service life, testing requirements, and operational life cycle cost.

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REQUIREMENT LESSONS LEARNED (A.3.14)

Sensitivity analysis can provide valuable information for the Program Office to make program decisions. The results will provide the justification of the selection of robust design vs. marginal design and the consequence of the design selection.

A.4.14 Sensitivity analyses.

Verification of 3.14 shall be accomplished by sensitivity analyses to evaluate the proposed structure's optimum design and to identify the performance, and cost impacts of more robust design options. The analysis shall include variation of parameters such as projected weight growth after IOC and performance and utilization severity in the selection of detailed structural configurations.

VERIFICATION RATIONALE (A.4.14)

A verified sensitivity analysis methodology is required to ensure the results of the sensitivity analysis can be used to assess variations of design options.

VERIFICATION GUIDANCE (A.4.14)

The airframe structural life can be significantly degraded by small variations in design parameters such as weight, maneuverability, mission usage, etc. The analysis methods to be used must have been verified and used in the similar programs before.

VERIFICATION LESSONS LEARNED (A.4.14)

A complete sensitivity analysis will yield important information for the Program Office to make Program Management decisions with the option to select structural robust design vs marginal design on the basis of system life cycle cost.

A.3.15 Force management.

Force management will be applied to the airframe structure during operational use and maintenance of the air vehicle. A data acquisition system is required that collects, stores, and processes data which can be used to support the force management systems/program.

REQUIREMENT RATIONALE (A.3.15)

Developing an airframe with adequate strength, rigidity, durability, and damage tolerance and maintaining these qualities depends on knowledge of individual operational usage. The Force Management program utilizes flight and landing usage data collected from the operation aircraft to determine cumulative fatigue damage, estimate fatigue life remaining, update structural maintenance and modification schedules, and provide design criteria for future aircraft modifications and replacement aircraft acquisition programs. Actual aircraft usage has historically varied substantially from development missions and mixes. Airborne flight data recorders (FDR) are needed to record individual aircraft usage and substantiate changes in operational mission usage. Airborne flight data recorders and the force management program are necessary to maximize the service life available based on each aircraft's individual usage, minimize impacts to operational readiness and structurally related maintenance costs and ensure acceptable levels of structural flight safety throughout the service life of the aircraft. Airborne flight data recorders are essential to ensure the successful life management of fleet airframe resources. Early involvement will help ensure a workable program.

REQUIREMENT GUIDANCE (A.3.15)

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Force management consists of collecting, storing, processing, and disseminating operational usage data throughout an aircraft's service life. The development of a force management system/program requires integration of airborne hardware and software, ground support hardware and software, and a fatigue life analysis or a crack growth analyses methodology and software with the aircraft structural development program. The contractor is normally responsible for development of the force management system/program, but it is to be developed jointly by the contractor and the procuring activity. A parallel engine management program should be integrated with the force management program to the extent compatible with the engine monitoring requirements. Additional information with respect to the airborne data acquisition system, ground/data handling and data processing can be found in AFFDL-TR-78-183, AFWAL-TR-81-3079, and ASD-TR-82-5012.

REQUIREMENT LESSONS LEARNED (A.3.15)

A.3.15.1 Data acquisition system provisions.

The data acquisition system shall be capable of recording operational usage data and shall be compatible with the airframe and all air vehicle systems when installed and used. The system shall interface with air vehicle systems and record the required data within required accuracies.

a. The data acquisition system shall meet the requirements of ___________________.

b. The data acquisition system shall be installed in _______________________.

c. Ground/Data Handling _______________________.

REQUIREMENT RATIONALE (A.3.15.1.a)

In order to monitor aircraft operational usage and flight/landing parameters, record structurally significant loading events, and derive loads environment and stress spectra (L/ESS), an airborne flight data recorder (FDR) is required.

REQUIREMENT GUIDANCE (A.3.15.1.a)

This blank should be filled by reference to plans and specifications for FDR hardware, new or to-be-developed, and the documentation needed to integrate new or existing FDR equipment into fleet aircraft. In addition, the contractor should also reference specifications and other documentation to describe how the FDR hardware and the data it records interfaces with the ground support equipment, maintenance concepts, and data processing facilities of the procuring activity.

The FDR should continuously monitor appropriate flight parameters and strains, and record significant damaging loading events necessary to determine the nominal strain history at each fatigue critical location. The following system capabilities should be considered when designing/selecting the airborne data acquisition system:

a. The system should measure, record, and store vertical accelerations, airspeed, altitude, fuel weight, total gross weight, real event time, and other aircraft parameters necessary to reconstruct that aircraft's usage history on a flight-by-flight basis.

b. The system should be able to accept in-coming signals from other aircraft systems which measure appropriate flight parameters, but should measure the parameter independently if it is not otherwise available. For instance, if pressure altitude readings are required but are not available from another aircraft system, the FDR hardware should include the capability to measure this parameter independently.

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c. The system should be capable of sampling the various aircraft parameter input signals at a rate, determined through analysis, such that the peak values of each signal can be recorded. All system sensors should have a range of measurement sufficient to cover the aircraft's complete flight envelope.

d. The system should be capable of identifying the real-time sequence, vice relative time sequence, of all recorded data using either an internal real-time clock or any other real-time clock signal from other aircraft systems.

e. The system should have a memory of sufficient size to store all of the FDR recorded aircraft parameters and usage events such that transfer of the data from the airborne FDR hardware will not need to occur more frequently than once per month.

f. The system should have a self-diagnostic capability and a method of indicating system failures or malfunctions which would require a maintenance action.

g. The system should store recorded data in non-volatile memory such that there are no system power requirements to maintain previously recorded usage data in the FDR memory while that aircraft is not flying.

h. The FDR should have the capability to measure direct strain readings for use in calculating fatigue damage, crack growth, or verifying structural response to changes in aircraft configuration, flight control systems, missions, or weights. Strain sensors should also be capable of recording unanticipated structural responses.

i. Strain sensor locations should be chosen in uniform or low-gradient strain fields which remain elastic under all load conditions up to 115% of limit load. Locations should also be chosen considering the accessibility of an area for routine sensor inspection and replacement, and should be protected from the normal service environment. Strain sensors should have a back-up sensor at all chosen sensor locations. The FDR system should indicate in the recorded data which strain sensor, primary or back-up, is operating at each sensor location. Each strain sensor location, primary and back-up, should have a reference output level defined by a full-scale test and verified by a flight demonstration program. The sensor should be mounted on a structural component or member such that the slope of the strain to load relationship for each sensor can be calibrated on the ground using simple testing procedures or in-flight using a reliable calibration flight maneuver.

j. The FDR system should be automated as much as possible with consideration given to multifunction capability, i.e., the same recording system could serve the structural recording and engine monitoring functions. Programmable, microprocessor computers with solid state memory should be given particular consideration. Historically, microprocessor based systems require less maintenance and data reformatting than the previously used magnetic tape or mechanical recorders.

The use of flight logs and other data gathering techniques may be applicable and should be included in the requirements as necessary.

REQUIREMENT LESSONS LEARNED (A.3.15.1.a)

Some current FDR systems record or transfer usage data on magnetic tape. This requires extensive ground processing of data such as reformatting, transcribing, and data compression before useful engineering data can be analyzed. Also, this system is subject to extensive delays in equipment maintenance because of the delays in processing data tapes. Other FDR programs using programmable, solid state microprocessors have eliminated the inherent problems with tape drive mechanisms. These microprocessor based systems have been used

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to perform multiple functions/duties (i.e. record structural usage, engine health/usage, and avionics performance data with data compression).

Strain sensors, although providing direct measurement and retention of an aircraft's local strain history, do require periodic maintenance as a result of sensor failures, mechanical damage, or environmental degradation. Strain sensors are also sensitive to location/alignment and there are also times where a "single sensor solution" for the structurally critical area is not always practical. The use of aircraft flight parameters and advanced regression analysis tools, such as neural networks, can yield local strain history results with the same accuracy as direct strain measurements. There are at least two significant advantages to the multiparameter recorder vice strain sensor recorder: (1) generally improved data recovery since several channels of the multiple parameter data would have to be lost before data reconstruction becomes unreliable; however, if the strain data is lost, most information needed to determine the local area strain history is lost and (2) if the critical structural areas change or if new tracking locations are added through service experience, all previously recorded/stored flight usage data can be reused to assess damage in these local areas; however, the strain data recorded/stored for discrete locations is generally valid only for the areas local to the strain sensor.

The sooner operational/maintenance personnel can determine airborne recorder faults/failures, suitable repairs can be completed and a minimal amount of aircraft usage data will be lost due to a non-functioning recorder; therefore, comprehensive system and sensor self-initiated tests have proven invaluable.

REQUIREMENT RATIONALE (A.3.15.1.b)

Aircraft must be instrumented with data acquisition system equipment to obtain individual aircraft operational usage and loading data.

REQUIREMENT GUIDANCE (A.3.15.1.b)

All fleet aircraft must be instrumented with data acquisition system equipment to obtain individual aircraft operational usage and loading data. The flight loads test aircraft must be instrumented to allow correlation of the loads and stresses derived from the airborne recorded parameters to those recorded during flight tests. Analysis methods and computer programs must be developed to record the initial and later phase of operational environment. In addition, all other flight test aircraft must be instrumented so that structural damage accumulated during air vehicle test and demonstration can be accounted for. The data acquisition system selected to accomplish the loads/environment spectra survey (L/ESS) task should be capable to capture at least 50% of the flight operational data before downloading.

REQUIREMENT LESSONS LEARNED (A.3.15.1.b)

The airborne data acquisition system must be specified in the original production contract for the aircraft system. If considered as a post-production retrofit effort, the resulting engineering change proposal could significantly increase the installation costs to account for engineering, integration, and logistics impacts. In addition, because post-production retrofit of airborne data acquisition hardware is viewed as an impact to cost, weight, and delivery schedule of the new aircraft without directly enhancing the performance or operational capability of the air vehicle, gaining program management approval for these engineering changes has been marginally successful.

REQUIREMENT RATIONALE (A.3.15.1.c)

As a system, the airborne data acquisition hardware is virtually useless unless recorded data can be successfully downloaded and transferred to the procuring activities central processing facility and subsequently processed to generate fatigue or crack growth life values for individual

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aircraft. The contractor must give proper consideration and significant thought to design/interface/integration details with the ground based support equipment to be used by the procuring activity to download/transfer recorded data or to the design/interface/integration of the software/hardware to be used to convert this recorded data into fatigue damage or crack growth life values.

REQUIREMENT GUIDANCE (A.3.15.1.c)

This blank should be filled by reference to plans and specifications for ground support equipment to be used to download and transfer usage data recorded by the airborne data acquisition system. In addition, the contractor should also reference specifications and other documentation (including structural analysis methods and reports, ground test reports, and flight test reports) to describe how the data recorded is converted from engineering units to local strain history and subsequently calculated cumulative fatigue damage or crack growth at each critical structural location.

The contractor should provide the functional description of aircraft ground support equipment required to download the data recorded by the airborne acquisition system, diagnose airborne acquisition system maintenance requirements and reconfigure airborne acquisition systems, as appropriate. The contractor should provide the functional description of any pre-processing requirements of the ground support equipment including procedures for merging flight log data (e.g. logbook hours, number/type of landings, mission use codes, etc.) with the recorded aircraft flight usage data. The contractor should describe step-by-step procedures to download usage data, diagnose airborne system health and reconfigure, as applicable, the airborne system for a specific aircraft installation.

The contractor should provide reference plans and documentation for the data processing procedures and analysis methods necessary to (1) determine the amount of missing or invalid aircraft usage data and replace/substitute for data gaps, (2) convert recorded aircraft usage data to local strains/stresses at each critical location,, (3) perform a "rain flow count" of the resulting variations of local stress/strain, and (4) compute and accumulate the fatigue damage or crack growth caused by each stress/strain cycle extracted by the rain flow. The fatigue analysis methods should be based on a local strain approach. For structures subject to random loadings, and where localized plasticity occurs at the critical location, the method selected should account for sequence effects and their impact on changing local residual stresses and the final damage computed. The analysis method should be correlated to the full scale and/or component fatigue/damage tolerance test such that lives calculated at critical locations correspond to test results/experience.

REQUIREMENT LESSONS LEARNED (A.3.15.1.c)

Data transfer using readily available, compact and reliable electronic media (such as 3 1/2" diskettes) have improved data recovery rates. In addition, the data stored in this medium can be copied to a local workstation for use by an analyst and, using other contractor or government developed software, convert the raw FDR data into engineering units, derive key information from the downloaded data (maximum N_z or 'g', total recorded flight time, etc.) and estimate damage or crack growth accumulated for the incremental flight data recorded. As aircraft life management continues to grow in importance, tools and routine procedures will be required which provide aircraft custodians the ability to review recorded data and perform service life analyses at the aircraft base of operations. Developing these tools as part of the overall force management program will provide the most accurate and streamlined processes for fleet operations to use.

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For several Navy fighter and attack aircraft programs, supplemental flight hour, mission, and landing usage data must be gathered and merged with the data recorded by the FDR during the downloading process. Current data acquisition systems record only relative time vice real time, making the effort of matching aircraft flight log information with the recorded usage data time consuming or sometimes impossible. Recent experience with recording the real time of the loading events has greatly improved the ease and accuracy of merging this supplemental data, which is also date/time cataloged.

For many Air Force and Navy aircraft, updating the methodology for life tracking has occurred at least once in the aircraft's lifetime. Regenerating individual aircraft spectra for rebaselining an aircraft's cumulative damage using new tracking algorithms is both time-consuming and expensive. The capability to generate and store the actual sequence of nominal strains for each aircraft for each tracking location on a monthly basis would minimize recalculation efforts.

A.4.15 Force management.

Verification of 3.15 and subparagraphs shall be accomplished by analyses and tests to ascertain that all requirements are met.

a. Analyses. Analyses which support the force management and maintenance concepts of the procuring activity are required to verify, for each fatigue critical location, that the individual aircraft tracking (IAT) methodology is updated and well correlated to full scale durability, damage tolerance, and flight load test results.

b. Tests. Demonstration tests shall be performed to verify that the data acquisition system records and processes all required aircraft systems and flight parameters necessary for the IAT methodology.

VERIFICATION RATIONALE (A.4.15)

A comprehensive test and analyses effort is required to develop and validate the operation of the aircraft data acquisition system and the individual aircraft tracking methodology selected.

VERIFICATION GUIDANCE (A.4.15)

An analysis methodology must be established to show compliance with the requirements of 3.15. The analysis methods must be calibrated to full scale durability, damage tolerance, and flight test results such that 100% of fatigue life expended or durability crack growth analysis calculated by the IAT methodology corresponds to one-half of the test demonstrated durability service life. The methodology should be verified by performing analysis with the IAT algorithm using the full scale durability and damage tolerance spectra of 3.11 and 3.12, respectively. These analyses shall be performed for each critical location being tracked, including:

a. For existing aircraft models, locations known to experience fatigue damage in service.

b. Locations experiencing fatigue damage during component or full scale durability and damage tolerance testing.

c. Locations having the lowest margins of safety based on durability and damage tolerance analysis using the appropriate design spectra where the margin of safety is defined as:

Margin of Safety (MS) = [(Analytically Predicted Life)/(Design Life)] - 1

Testing shall also be performed to evaluate, for all flight and structural parameters, the accuracy of the data measured and recorded by the data acquisition system against corresponding measurements from the tests of 4.10.5, 4.10.7, 4.11.1.2.2, and 4.12.2, as applicable.

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In addition, the contractor shall test and demonstrate all aspects and capabilities of the force management data processing program. This should be accomplished using data from the FDR collected during tests of 4.10.7 and other demonstration flight testing, to demonstrate the ability to download data from the airborne acquisition system, transfer the data to the appropriate transfer media, merge the recorded data with the applicable supplemental logbook information, identify missing/invalid data, convert the recorded data into fatigue damage values, generate and store nominal strain spectra for the aircraft, and produce monthly incremental information/data files for each aircraft, including bureau/tail number, custodian, total flight hours, total landings (field and ship-based, as applicable), cumulative N_z exceedances, incremental/total fatigue damage or crack growth accrual values, and other pertinent information required to track service life of aircraft in consonance with the force management and maintenance concepts of the procuring activity.

VERIFICATION LESSONS LEARNED (A.4.15)

A.3.16 Production facilities, capabilities, and processes.

The manufacturing system shall have the facilities, capabilities, processes, and process controls to provide products of consistent quality that meet performance requirements. Key production processes shall have the stability, capability, and process controls to maintain key product characteristics within design tolerances and allowables.

REQUIREMENT RATIONALE (A.3.16)

To minimize production risk, to maintain design tolerances during the manufacturing process, and to control product cost and quality in production, it is essential to identify, quantify, qualify, and control key production processes. This requirement is intended to ensure the contractor applies the same discipline and effort to the qualifications of the production processes as previously done for performance of primary mission equipment. By identifying and qualifying key production processes up front, production will be smoother and subsequent process improvement efforts can be directed to control cost and quality.

REQUIREMENT GUIDANCE (A.3.16)

REQUIREMENT LESSONS LEARNED (A.3.16)

History is replete with development programs which have experienced severe problems in production. Under past practices, development was primarily oriented to the demonstration of product performance with little attention to the ability to consistently and predictably produce the required product characteristics in a cost effective manner. In many cases, the product designs were completed and then turned over to manufacturing who attempted to optimize the production implementation within existing plant capabilities. Little or no effort had been made during development to address producibility as part of the design process. In addition, process control is not a norm within the current aerospace industry. In many cases, therefore, process capability is not known, let alone matched to product requirements. Mismatches between design limits and process capabilities are discovered too late - in real time under the pressure of delivery schedules. Resulting design or process changes are generally sub-optimal.

A.4.16 Production facilities, capabilities, and processes.

These requirements shall be incrementally verified by examination, inspections, analyses, demonstration, and/or test. The incremental verification shall be consistent with the expectations for design maturity expected at key decision points in the program.

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VERIFICATION RATIONALE (A.4.16)

Incremental verification is employed to mitigate the risk associated with production, to ensure the ability to maintain design tolerances during the manufacturing process, and to confirm that the contractor has a process to control production cost and quality in production.

Verification at the aircraft structures level verifies that the contractor has established a disciplined approach with a process development strategy that (1) includes pre-planned process improvement and evolutionary strategies, (2) provides for the identification and risk abatement of high risk production identification and control of key processes, (4) ensures consistency between process performance, product performance, can cost, (5) defines quality assurance requirements consistent with product performance and cost requirements, (6) flows these requirements to the subtier contractors, and (7) is consistent with the approach at the weapon system level.

Key product characteristics are those measurable design details that have the greatest influence on the product meeting its requirements (form, fit, function, cost, service life, etc.) and are documented in a manner processes within the program's overall risk management process, (3) includes the determined by the contractor on the drawings and supporting Technical Data Packages in the "Build-To" and "Support" Packages. Key production processes follow logically from the identification of key product characteristics and the selection of production processes. Key production processes are those processes associated with controlling those key product characteristics. The identification of the key process requirement is accomplished through the system engineering process and design trade studies to establish a cost effective design.

In general, production cost risk can be controlled by demonstrating the key process requirements which include the establishment of design limits and process capabilities. Process capability is typically defined in terms of the statistical probability of non-conformance, such as defects per million or Cp, which is the ratio of design limits to the process variation. Once process capability requirements are established and the capability of the key processes verified, the process controls are established for use during production.

The identification of key product characteristics and key processes, and the establishment of process capability and process control requirements occur at the aircraft structure and subtier levels. Tasks essential to accomplishing this are (1) identification of high risk production processes with appropriated risk abatement activities, (2) identification and documentation of key product characteristics, (3) identification of key production processes and their key process characteristics, (4) establishing the process requirements, which include both the design limits and the process capability, (5) determination of the actual process capability, (6) establishing the process control requirements, and (7) flow down of these requirements to the suppliers whose products will have an effect on the system's attainment of performance requirements. Therefore, verification at the aircraft structure level confirms compliance with requirements at the aircraft structure level, that appropriate requirements are flowed down to the subtier level, and that essential tasks have been accomplished at the appropriate aircraft structure/subtier level.

VERIFICATION GUIDANCE (A.4.16)

The following incremental verifications should be accomplished early in a program such as prior to the System Functional Review (SFR). Examine and analyze documentation to verify that the contractor has a process documented and in place that (1) establishes a process technology development strategy including pre-planned process improvement and evolutionary strategies, (2) identifies, as part of the overall program risk management process, high risk production processes and risk abatement activities, (3) provides for the early identification of key product

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characteristics, key processes, and their key characteristics, (4) assesses key process technology performance, availability, and suitability, (5) establishes process capability requirements (Cpk), (6) verifies actual process capabilities, (7) establishes and implements process controls with minimal inspections, (8) flows down requirements to all subtier levels, and (9) is consistent with the overall weapon system level requirements and approach. This verifies the contractor's readiness for the next phase or engineering effort by ensuring that the contractor has a working process in place to identify, develop, and control key manufacturing processes.

Early identification of critical manufacturing process technology performance, availability, and suitability, with the implementation of an appropriate strategy, reduces production risks by allowing the manufacturing processes to be developed and matured prior to full-scale production.

The following incremental verifications should be accomplished prior to 20% drawing releases or Preliminary Design Review (PDR). Examine and analyze documentation and design trade study reports to confirm the following have been accomplished at the appropriate aircraft structure/subtier levels: (1) manufacturing feasibility assessment, (2) identification of key product characteristics and the documentation of those characteristics on drawings including appropriate geometric tolerancing and datum control, (3) identification of key processes, (4) establishment of process capability requirements, which include both the design limits and process capabilities (Cpk. defects per million, etc.), (5) evaluation of key process capabilities, (6) flow down of key process requirements, and (7) assessment of risk abatement status on high risk production processes and appropriate action taken is needed. This verification ensures that an appropriate manufacturing process has been developed and the preliminary design to address manufacturing processes has been confirmed to be complete, correct, and adequate.

Usually, the fidelity of the design at PDR is such that all key product characteristics and key production processes are not yet identified. However, based on historical data and the existing level of design, an initial identification and assessment of key production processes can be accomplished and initial capability requirements should be established. In addition, sufficient information exists to assess the progress of risk abatement activities for high risk production processes.

The following incremental verifications should be accomplished prior to 80% drawing release or Critical Design Review (CDR). Examine and analyze documentation and design trade study reports to confirm the following have been accomplished at the appropriate aircraft structure/subtier levels (1) more reined effort of the verification done at PDR to reflect expected design maturity at CDR, (2) completion of preliminary specifications for key processes, (3) completion of preliminary process control plans, (4) documentation of rationale to support the detailed design (product/special tooling/special test equipment/support equipment) including key product characteristic's design limit sensitivity to off nominal production (details to include the results of key suppliers' efforts), (5) documentation of rationale to support selection of production processes, including comparison of required process capabilities to documented capabilities and selection of process control criteria with the associated process control plan for achieving required product quality, and (6) definition of verification requirement for key processes including facility capabilities. This verification ensures that manufacturing process development and the detail design to address manufacturing processes has occurred and has been confirmed to be complete, correct, and adequate.

Usually the fidelity of the design at CDR is such that all key product characteristics and key production processes are identified, capability requirements established, process capabilities

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verified, and preliminary process control plans completed. In addition, sufficient information exists to assess the progress of risk abatement activities including the demonstration of process capability for high risk production processes.

The following incremental verifications should be accomplished prior to System Verification Review (SVR). Examine and analyze documentation and design trade study reports to confirm the following have been accomplished at the appropriate aircraft structure/subtier levels (1) identification of all key product characteristics and the documentation of those characteristics on drawings including appropriate geometric tolerancing and datum control, (2) establishment of process capability requirements, which include both the design limits and process capabilities, (3) verification of key process capabilities complete including validated process control plans, (4) completion of final process control plans, (5) proof of final manufacturing feasibility including facility capability, (6) completion of final specifications for all key production processes, and (7) completion of contractor build-to documentation. This verification requirement ensures that manufacturing process development, detail design to address manufacturing processes, and contractor build-to documentation has occurred and has been confirmed to be compete, correct, adequate and stable, and ensures the system is ready for the production phase.

The fidelity and stability of the design at SVR is such that all key product characteristics and key production processes are identified, capability requirements established, process capabilities verified, process control plans completed, and contractor build-to package completed. Risk abatement activities should have lowered key production process risk to an acceptable level for start of production.

The following incremental verifications should be accomplished prior to Physical Configuration Audit (PCA). Examine documentation to confirm that the adequacy and completeness of the build-to documentation was verified at the aircraft structure and subtier level. This verification requirement is to determine the completeness, correctness, and adequacy of the final build-to documentation.

VERIFICATION LESSONS LEARNED (A.4.16)

A.3.17 Engineering data requirements.

Engineering data for all studies, analyses, and testing generated in accordance with the performance and verification requirements for loads, strength, rigidity, vibroacoustics, corrosion prevention and control, materials and processes selection, application and characterization, durability and damage tolerance, force management, and all other requirements of this specification (as identified) shall be documented. All data bases used to establish, assess and support inspections, maintenance activities, repairs, modification tasks, and replacement actions for the life of the airframe shall be documented. Engineering data shall be consistent with and supportive of all milestones identified in the verification matrix activities identified in 4.0.

REQUIREMENT RATIONALE (A.3.17)

Engineering data must be documented, preserved, and available for use in establishing design requirements, assessing compliance with performance, and verification of requirements, and to manage, support, and maintain the aircraft throughout its life.

REQUIREMENT GUIDANCE (A.3.17)

The effectiveness of any military force depends in part on the operational readiness of weapon systems. One major item of an aircraft system affecting its operational readiness is the

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condition of the airframe structure. To establish the adequacy of the design to meet operational and support requirements, the capability of the airframe structure must be established, characterized, and documented. Establishing these characteristics and thereby implementing a successful Aircraft Structural Integrity Program requires the production, compilation, and documentation of engineering data used in assessing compliance with structural performance requirements.

Such engineering data is necessary to:

a. Establish, evaluate, and substantiate the overall structural integrity (strength, rigidity, damage tolerance and durability, producibility, and supportability) of the airframe structure.

b. Acquire, evaluate, and utilize operational usage data to provide a continual assessment of the in-service integrity of individual aircraft.

c. Provide a basis for determining and implementing tasks associated with logistics and force planning requirements (maintenance, inspections, supplies, rotation of aircraft, deployment, retirement, and future force structure.)

d. Provide a basis for continuous improvement of structural criteria, design methods, evaluation, and substantiation of future aircraft.

The process of identifying, using, and preserving engineering data for use in establishing, evaluating, and substantiating compliance with performance and verification requirements for the airframe structure is well defined in the five tasks outlined in MIL-HDBK-1530. These five tasks should be considered in developing the specific engineering data requirements for the airframe.

REQUIREMENT LESSONS LEARNED (A.3.17)

A.4.17 Engineering data requirements verification.

Data requirements content and format for studies, analyses, and test requirements shall be selected from the DOD Authorized Data List and shall be reflected in the contractor data requirements list (DD Form 1423) attached to the request for proposal, invitation for bids, and the contract as appropriate. Documentation and submittal of data and on-site review requirements shall be in accordance with and supportive of the activities identified in 4.0 and shall be subject to approval of the procuring activity. The documentation of the data shall also be compatible with generation and support of technical orders and maintenance plans, and allow the using command a database to support and manage the aircraft throughout its life.

VERIFICATION RATIONALE (A.4.17)

Documentation of engineering data in a uniform and timely manner is necessary to ensure that requirements are met. It is essential that the data be compatible with generation and support of technical orders, and allow the using command a database to support and manage the aircraft throughout its life.

VERIFICATION GUIDANCE (A.4.17)

When this specification is used in an acquisition which incorporated a DD Form 1423, Contract Data Requirements List (CDRL), the data requirements identified below shall be developed as specified by an approved Data Item Description (DD Form 1664) and delivered in accordance with the approved CDRL incorporated into the contract. When the provisions of DAR 7-104.9(n)(2) are invoked and the DD Form 1423 is not used, the data specified below shall be delivered by the contractor in accordance with the contract or purchase order requirements.

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Deliverable data required by this specification is cited in the following paragraphs. Each data requirement has been assigned a recommended submittal category.

a. Category I. Information and data assigned to this category is generated by the contractor in response to the contract requirements, but is retained by the contractor in contractor format. This category is applicable and may result in deliverable data if the CDRL, DD Form 1423, incorporates a Data Item Description line item for DI-A-3027 Data Accession List/Internal Data. or if the contract contains an equivalent data requirement.

b. Category II. Information and data assigned to this category is generated and submitted by the contractor in response to the contract requirements and the applicable line items of the CDRL, DD Form 1423. These items are not to be submitted for approval, i.e. the Block 8 of the DD Form 1423 should contain a "D", "N", or are blank. See DI-A-23434 for definition of codes.

c. Category III. Information and data assigned to this category is generated and submitted by the contractor in response to the contract requirements and the applicable line items of the CDRL, DD Form 1423. These items are to be submitted for approval, i.e. the Block 8 of the DD Form 1423 should contain an "A", "AD", or "AN". Approval clarification instructions for an "A", "AD", or "AN" in Block 8 must be included in Block 16.. See DI-A-23434 for definition of codes and approval clarification instructions.

Table XXXV provides a listing of data item descriptions typically used in airframe development and modification programs. The guidance for submittal of data in accordance with these formats varies depending on the type of data to be generated and documented. Generally, data delivery dates in advance of the milestones the data items are intended to support are a function of the complexity of the data and the potential impact on successfully passing milestone criteria. As a general rule, documentation of trade studies, sensitivity studies, and analyses should be available for the procuring activity review not less than 90 days prior to the milestone for which that data will be used. Test plans should be made available for the procuring activity review not less than 60 days prior to the test readiness review. Depending on the impact of the test results, data summarizing execution and results of test should be documented and available for the procuring activity review not longer than 90 days after completion of the test.

VERIFICATION LESSONS LEARNED (A.4.17)

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ACRONYMS

A

ACO	Administrative Contracting Officer
ADS	Air delivery system
AEW	Aircraft early warning
AGL	Above ground level
AIAC	Aircraft monitor and control
AIS	Avionics intermediate shop
ANG	Air National Guard
APU	Auxiliary power unit
ARI	Aileron rudder interconnect
ASE	Aeroservoelastic
ASW	Anti-submarine warfare

B

BLW	Basic landing weight
BNS	Bomb navigation system

C

CAS	Calibrated airspeed
CDRL	Contract Data Requirements List
CDS	Container delivery system
cg	Center of gravity
CPAB	Corrosion Prevention Advisory Board
Cp	Process capability index
Cpk	Process performance index
CS	Constant speed drive
CSV	Constant selector valve

D

da/dn	Crack growth rate
DAL	Data accession list
DAR	Defense Acquisition Regulation
dB	Decibel
DD	Data documentation
DF	Dynamic factor
DLL	Design limit load
DoD	Department of Defense
DoDISS	Department of Defense Index of Specifications and Standards

E

EAS	Equivalent air speed
ECM	Electronic countermeasures
ECP	Engineering change proposals
ECS	Environmental control system
EMD	Engineering and Manufacturing Development
EMI	Electromagnetic interference
EMP	Electromagnetic pulse
EPA	Environmental Protection Agency

F

f	Applied stress
F	Allowable stress
FCAS	Flight control augmentation system
F/CGMS	Fuel/center of gravity management system
FCLP	Field carrier landing practice
FLM	Field level maintenance
FOD	Foreign object damage
fps	Feet per second
FSD	Full scale development

G

g	Acceleration = 32.2 ft/sec^2
g	Damping coefficient

I

IAS	Indicated airspeed
IAT	Individual Aircraft Tracking
IFR	Instrument flight rule
IOC	Initial operation capability
IP	Instrument pilot
ISO	Isochronal

J

JBD	Jet blast deflector

K

k	Special factor
KIAS	Knots indicated airspeed

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KTAS	True air speed in knots

L

L	Longitudinal
LAPES	Low altitude parachute extraction system
lbs	Pounds
LH	Left hand
LOX	Liquid oxygen
LRU(s)	Line replaceable unit(s)
LT	Long transverse

M

M	Mach
M	Maintainability
MER	Multiple ejection racks
M_L	Maximum Mach
MLG	Main landing gear
MS	Margin of safety

N

NAEC	Naval Aeronautical Engineering Center
NDT/I	Nondestructive testing/inspection
NLG	Nose landing gear
NM	Nautical miles

P

PA	Product assurance
PCO	Procuring Contracting Officer
PLAT	Pilot landing aided television
PMD	Program Management Directive
PSD	Power spectral density
PSI	Pounds per square inch
PVC	Polyvinylchloride
P_{XX}	Internal member load
P_{YY}	Internal member load for fail-safe structure

Q

q	Maximum permissible dynamic pressure
QA	Quality assurance

R

R	Reliability
RCS	Ride control system
RDT&E	Research development test and evaluation
RFP	Request for proposal
RH	Right hand
RPM	Revolutions per minute

S

SCN	Specification change notice
SON	Statement of need
SOW	Statement of work
SPC	Statistical process control
SPO	System Program Office
SPU(s)	Station program unit(s)
SRM	Structural repair manual
SS	System safety
ST	Short transverse

T

TAS	True air speed
TASTCTO	Time Compliance Technical Order
TER	Triple ejection racks
TFR	Terrain following radar
TO	Technical Order

V

V_A	Maneuver speed
V_C	Launch end speed
V_D	Dive speed
V_e	Equivalent air speed
V_E	Engaging speed
V_G	Gust limit speed
V_H	Maximum level flight speed
V_{HD}	Maximum speed hook extended
VIP	Very Important Person (Presidential Vehicles)
V_L	Limit speed

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V_{LF}	Limit speed take-off and landing
V_{LO}	Lift-off speed
V_{S1}	Maneuver stall speed
V_{SF}	Maximum speed for system failure
V_{SL}	Landing stall speed
V_T	Taxi speed
V_{TD}	Touch down speed
V_{TDC}	Shipboard recovery speed
V_V	Landing sink rate
	W
WSEM	Weapons systems evaluator missile
WSO	Weapons system officer
WOD	Wind over deck
	Y
Y_d	Limit gust velocity

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TABLE I. Airframe and landing gear structural failure accidents (1968 to 1978).

Total	328	
	Class of Accident	Percent
Major		41
Minor		59
	Mission Phase - Ground (1)	Percent
Engine Start		1.5
Taxi		2.5
Braking		0.3
Turning		1.2
T.O. Roll		15.9
Landing T.O.		16.2
Landing Roll		27.4
	Mission Phase - Flight (1)	Percent
Climb		4.6
Cruise		13.4
Refuel		0.9
Maneuver		8.2
Descent		1.5
Landing Pattern		6.1
	Inspection (1)	Percent
Ground		0.3
	0% 25% 50% 75% 100%	

NOTES:

(1). When the problem or emergency was first detected or initiated which resulted in the accident or report.

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TABLE II. Breakdown of accidents by cause, component, and type of failure.

Reported Cause	Percent
Inadequate Design	4.9
Material	22.6
Technical Data	3.4
Not I.A.W. T.O.'s or	8.5
P.R.'s(1)	1.2
Poor Repair	28.7
Pilot	2.1
Other Personnel	15.8
Equipment Malfunction	8.2
Other	4.6
Unknown	
0% 25% 50% 75% 100%	
Accidents by Components (2)	**NR/NR**
Landing gear - Structure	50/163
Landing gear - Other	52/2
Wing - Structure	25/23
Wing - Other	4/0
Horizontal tail - Structure	1/3
Horizontal tail - Other	0/1
Vertical tail - Structure	2/4
Vertical tail - Other	0/0
Cockpit - Structure	4/1
Cockpit - Other	5/0
Other - Structure	0/4
Other - Other	1/0
Control system - Structure	0/0
Control system - Other	3/0
Engine	21/1
Type of Structural Failure Involved/Initiated (2)	**NR/NR**
Overload	11/185
Fatigue	18/1
Crack	11/0
Corrosion·	16/2
Understrength	7/0
Temperature	0/2
Loose part	2/0
Unknown	22/9
Other	2/0
Component Motion (2)	**NR/NR**
Collapse	46/161
Diverge	31/14
Shimmy	2/3
Gear Retracted	13/2
0% 50% 100% 150% 200%	

NOTES:

(1). Not I.A.W. T.O.'s or P.R.'s: Not in accordance with technical orders or purchase requests.

(2). More than one component, type of failure and component motion may be involved in accident.

Primary Cause/Factor of Accident

Secondary or Induced Failure or Factor of Accident

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TABLE III. Accidents attributed to landing gears and wings.

Accidents Attributed to Landing Gear (Cause)

	Total	Attack	Fighter	Trainer	Bomber	Cargo	Utility
Material	44	5	19	3	4	10	3
Inadequate Design	1	0	0	0	0	1	0
Not I.A.W. T.O.s or P.R.s(1)	2	0	0	0	0	2	0
Unknown	3	1	2	0	0	0	0
				Breakdown by Type of Failure			
Corrosion	13	0	4	2	2	5	0
Understrength	7	0	7	0	0	0	0
Cracked	6	0	1	0	1	3	1
Fatigue	6	0	3	1	0	2	0
Overload	5	2	0	0	1	2	0
Unknown	12	4	6	0	0	0	2
Other	1	0	0	0	0	1	0
				Breakdown by Mission Phase			
Taxi	5	0	0	0	1	4	0
Turning	4	0	1	0	2	1	0
Take-off	7	2	3	1	1	0	0
Landing Touch Down	16	3	8	1	0	4	0
Landing Roll	18	1	9	1	0	4	3

Accidents Attributed to Wing (Cause)

	Total	Attack	Fighter	Trainer	Bomber	Cargo	Utility
Material	21	1	7	6	5	2	0
Inadequate Design	2	0	0	0	0	2	0
Unknown	2	1	1	0	0	0	0
				Breakdown by Type of Failure			
Corrosion	3	0	1	2	0	0	0
Cracked	4	1	2	1	0	0	0
Fatigue	9	0	3	2	2	2	0
Overload	2	0	0	0	0	2	0
Loose Part	1	0	0	0	1	0	0
Unknown	6	1	2	1	2	0	0
				Breakdown by Mission Phase			
Take-off	1	0	0	0	0	1	0
Climb	5	0	1	0	3	1	0
Cruise	3	0	1	0	1	1	0
Maneuver	14	2	6	6	0	0	0
Landing Pattern	1	0	0	0	1	0	0
Other	1	0	0	0	0	1	0

(1). Not I.A.W. T.O.s or P.R.s: Not in accordance with technical orders or purchase requests.

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TABLE V. Production aircraft weight growth.

Weight Term	Weight Growth	
	Bombers(1)	Cargo Aircraft(2)
Take-off Gross Weight	+1.42% per year	+1.07% per year
Fuel Weight	+0.41% per year	+1.34% per year
Zero Fuel Weight	+2.01% per year	+1.14% per year
Operation Weight	+1.47% per year	+1.24% per year
Weight Empty	+1.93% per year	+1.29% per year

(1). Average of B-47, B-52, B-58, B-70 (33 aircraft data base)
(2). Average of C-5A, C-121, C-124, C-130, C-133, C-135, KC-135, C-141 (58 aircraft data base)

TABLE VI. Hot temperature values.

AREA	MAXIMUM TEMPERATURES (^{o}F)		
DESCRIPTION	SOAK	SUSTAINED	INTERMITTENT
Fwd Avionic Bay		160	203
Gun Bay		185	210
Nose Wheel Well		160	203
Cockpit Area	200	130	
Conditioning Compartment			215
External Skin		185	210
Engine Bay and Tail Cone		250 to 900	
Drag Chute Container		185	250

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TABLE VII. Low Energy Impact (Tool Impact)

Zone	Damage Source	Damage Level	Requirements in addition to Paragraph 3.11.1
1 High Probability of Impact	* 0.5 in. dia. solid impactor * low velocity * normal to surface	Impact energy smaller of 6 ft-lbs or visible damage (0.1 in. deep) with min. of 4 ft-lbs.	* no functional impairment or structural repair required for two design lifetimes and no water intrusion * no visible damage from a single 4 ft-lb impact
2 Low Probability of Impact	Same as Zone 1	Impact energy smaller of 6 ft-lbs or visible damage (0.1 in. deep)	* no functional impairment after two design lifetimes and no water intrusion after field repair if damage is visible

TABLE VIII. Low Energy Impact (Hail and Runway Debris)

Zone	Damage Source	Damage Level	Requirements in addition to Paragraph 3.11.1
All vertical and upward facing horizontal surfaces	Hail: * 0.8 in. dia. * sp. Gr. = 0.9 * 90 ft/sec * normal to horizontal surfaces * 45 deg. angle to vertical surfaces	Uniform density 0.8 in. on center	* no functional impairment or structural repair required for two design lifetimes * no visible damage
Structure in path of debris	Runway debris: * 0.5 in. dia. * sp. Gr. = 3.0 * velocity appropriate to system	N/A	* no functional impairment after two design lifetimes and no water intrusion after field repair if damage is visible

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TABLE IX. Initial Flaw/Damage Assumptions.

Flaw/Damage Type	Flaw/Damage Size
Scratches	Surface scratch 4.0" long and 0.02" deep
Delamination	Interply delamination equivalent to a 2.0" diameter circle with dimensions most critical to its location
Impact Damage	Damage from a 1.0" diameter hemispherical impactor with 100 ft-lbs of kinetic energy or with that kinetic energy required to cause a dent 0.10" deep, whichever is less.

TABLE X. Residual Strength Load.

P_{XX}(1)	Degree of Inspectability	Typical Inspection Interval	Magnification Factor, M(3)
P_{FE}	In-Flight Evident	One Flight(2)	100
P_{GE}	Ground Evident	One Day (Two Flights)(2)	100
P_{WV}	Walk-Around Visual	Ten Flights(2)	100
P_{SV}	Special Visual	One Year	50
P_{DM}	Depot or Base Level	1/4 Lifetime	20
P_{LT}	Non-Inspectable	One Lifetime	20

(1) P_{XX} = Maximum average internal member load (without clipping) that will occur once in M times the inspection interval. Where P_{DM} or P_{LT} is determined to be less than the design limit load, the design limit load should be the required residual strength load level. P_{XX} need not be greater than 1.2 times the maximum load in one lifetime, if P_{XX} is greater than the design limit load.
(2) Most damaging design mission.
(3) See 3.12.2.a.

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TABLE XI. Turbulence field parameters.

Altitude (ft)	Mission Segment	Direction(1)	P_1	b_1 (ft/sec)	P_2	b_2 (ft/sec)	L (ft)(2)
0 - 1,000	Low level contour	Vertical	1.00	2.7	10^{-5}	10.65	500
0 - 1,000	Low level contour	Lateral	1.00	3.1	10^{-5}	14.06	500
0 - 1,000	Climb, cruise, descent	Vertical & Lateral	1.00	2.51	.005	5.04	500
1,000 - 2,500	Climb, cruise, descent	Vertical & Lateral	.42	3.02	.0033	5.94	1750
2,500 - 5,000	Climb, cruise, descent	Vertical & Lateral	.30	3.42	.0020	8.17	2500
5,000 - 10,000	Climb, cruise, descent	Vertical & Lateral	.15	3.59	.00095	9.22	2500
10,000 - 20,000	Climb, cruise, descent	Vertical & Lateral	.062	3.27	.00028	10.52	2500
20,000 - 30,000	Climb, cruise, descent	Vertical & Lateral	.025	3.15	.00011	11.88	2500
30,000 - 40,000	Climb, cruise, descent	Vertical & Lateral	.011	2.93	.000095	9.84	2500
40,000 - 50,000	Climb, cruise, descent	Vertical & Lateral	.0046	3.28	.000115	8.81	2500
50,000 - 60,000	Climb, cruise, descent	Vertical & Lateral	.0020	3.82	.000078	7.04	2500
60,000 - 70,000	Climb, cruise, descent	Vertical & Lateral	.00088	2.93	.000057	4.33	2500
70,000 - 80,000	Climb, cruise, descent	Vertical & Lateral	.00038	2.80	.000044	1.80	2500
above 80,000	Climb, cruise, descent	Vertical & Lateral	.00025	2.50	0	0	2500

Notes:
(1). Parameter values labeled Vertical & Lateral are to be used equally in both the verticla and lateral directions.
(2). For altitudes below 2,500 ft, the scale of turbulence, L, can be assumed to vary directly with altitude.

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TABLE XII. Towing conditions.

<table>
<tr><th rowspan="2">Condition</th><th colspan="2">Towing load</th><th rowspan="2">Rotation of auxiliary wheel relative to normal position</th><th rowspan="2">Tow point</th></tr>
<tr><th>Direction from forward, degrees</th><th>Magnitude</th></tr>
<tr><td>1</td><td>0</td><td rowspan="4">0.75 T</td><td rowspan="4"></td><td rowspan="4">At or near each main gear</td></tr>
<tr><td>2</td><td>±30</td></tr>
<tr><td>3</td><td>180</td></tr>
<tr><td>4</td><td>±150</td></tr>
<tr><td>5</td><td>0</td><td rowspan="2">T</td><td rowspan="2">0</td><td rowspan="8">At auxiliary gear or near plane of symmetry</td></tr>
<tr><td>6</td><td>180</td></tr>
<tr><td>7</td><td>0</td><td rowspan="2">T</td><td rowspan="2">180</td></tr>
<tr><td>8</td><td>180</td></tr>
<tr><td>9</td><td>Maximum angle</td><td rowspan="2">0.5 T</td><td rowspan="2">Maximum angle</td></tr>
<tr><td>10</td><td>Maximum angle plus 180</td></tr>
<tr><td>11</td><td>Maximum angle</td><td rowspan="2">0.5 T</td><td rowspan="2">Maximum angle plus 180</td></tr>
<tr><td>12</td><td>Maximum angle plus 180</td></tr>
</table>

TABLE XIII. Jacking loads.

<table>
<tr><th>Component</th><th>Landing Gear 3-Point Attitude</th><th>Other Jack Points Level Attitude</th></tr>
<tr><td>Vertical</td><td>1.35 F</td><td>2.0 F</td></tr>
<tr><td>Horizontal</td><td>0.4 F</td><td>0.5 F</td></tr>
<tr><td colspan="3">F is the static vertical reaction at the jack point.</td></tr>
</table>

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TABLE XIV. Seat crash load factors.

Basic Mission Symbols	Load Factors				Applicable Items
	Longitudinal		Vertical	Lateral	
	Forward	Aft		(Left and Right)	
All Airplanes Except C	40	20	10 Up 20 Down	14	Applicable to all items
	20	10	10 Up 20 Down	10	Applicable to all items except stowable troop seats
C	10	5	5 Up 10 Down	10	Applicable to stowable troop seats

TABLE XVI. Failure occurrences vs. load at failure.

Percent of Ultimate Load	Number of Failures	Cumulative Number of Failures	Cumulative Percent of Failures
45	1	1	2
50	1	2	5
55		2	5
60		2	5
65	2	4	9
70	1	5	12
75	1	6	14
80	5	11	26
85	5	16	37
90	10	26	60
94	9	35	81
98	6	41	95
100	2	43	100

Failures in 8 different test programs. Considered only major structure.
419 Total tests involved
43 Failures (10%) occurred
376 Tests (90%) to ultimate load without failure

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TABLE XVII. WPAFB static tests first failure of major components, 1940 through 1948.

Percent Ultimate Load	Number of Failures		Cumulative Number of Failures		Cumulative Percent of Failures	
	Low	High	Low	High	Low	High
35	1	1	1	1	.2	.2
40	13	6	14	7	3.2	1.6
42	1	1	15	8	3.5	1.9
50	5	3	20	11	4.6	2.6
51	1	1	21	12	4.9	2.8
53	2	2	23	14	5.3	3.2
55	5	4	28	18	6.5	4.2
58.5	1	1	29	19	6.7	4.4
60	13	14	42	33	9.7	7.7
62	1	1	43	34	10.0	7.9
65	2	2	45	36	10.4	8.4
67	3	3	48	39	11.1	9.0
68	1	1	49	40	11.4	9.3
70	11	11	60	51	13.9	11.8
75	4	4	64	55	14.8	12.8
77	2	2	66	57	15.3	13.2
78	1	1	67	58	15.6	13.5
80	30	37	97	95	22.5	22.0
85	4	3	101	98	23.4	22.7
87	1	1	102	99	23.7	23.0
90	27	26	133	129	30.9	29.9
93	1	1	134	130	31.1	30.2
95	15	14	149	144	34.6	33.4
96	1	1	150	145	34.8	33.6
98	7	7	157	152	36.4	35.3
100	274(1)	279(1)	431	431	100.0	100.0

NOTE: First failure in major components, i.e. landing gear, fuselage, wing, horizontal tail and vertical tail.
(1). No failure.

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TABLE XVIII. WPAFB static test first failure of airplane, 1940 through 1948.

Percent Ultimate Load	Number of Failures		Cumulative Number of Failures		Cumulative Percent of Failures	
	Low	High	Low	High	Low	High
35	1	1	1	1	.9	.9
40	12	6	13	7	11.3	6.1
45	1	1	14	8	12.2	7.0
50	4	3	18	11	15.7	10.0
55	8	7	26	18	22.6	15.7
58.5	1	1	27	19	23.5	16.7
60	4	7	31	26	26.9	22.6
65	3	3	34	29	29.6	25.2
70	8	8	42	37	36.5	32.2
75	3	3	45	40	39.1	34.8
80	14	18	59	58	51.3	50.4
85	2	1	61	59	53.0	51.3
90	11	12	72	71	62.6	61.7
95	9	8	81	79	70.4	68.7
<100	7	7	88	86	76.5	74.8
100	27(1)	29(1)	115	115	100.0	100.0

NOTE: Landing gear, fuselage, wing, horizontal tail, and vertical tail test results used.
(1). No failure.

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TABLE XIX. WPAFB static tests first failure of major components, 1950 through 1976.

Percent Ultimate Load	Number of Failures		Cumulative Number of Failures		Cumulative Percent of Failures	
	Low	High	Low	High	Low	High
40	3	1	3	1	2.9	1.0
45	1	0	4	1	3.9	1.0
50	0	1	4	2	3.9	1.9
53	1	1	5	3	4.9	2.9
60	3	4	8	7	7.8	6.8
65	1	1	9	8	8.7	7.8
67	1	1	10	9	9.7	8.7
70	4	1	14	10	13.6	9.7
75	0	3	14	13	13.6	12.6
76	1	1	15	14	14.6	13.6
80	9	6	24	20	23.3	19.4
85	2	3	26	23	25.2	22.3
88	1	1	27	24	26.2	23.3
90	6	9	33	33	32.0	32.0
91	1	1	34	34	33.0	33.0
94	1	1	35	35	34.0	34.0
95	4	3	39	38	37.9	36.9
97	1	1	40	39	38.8	37.9
100	63(1)	64(1)	103	103	100.0	100.0

NOTE: First failure in major components, i.e. landing gear, fuselage, wing, horizontal tail and vertical tail.
(1). No failure.

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TABLE XX. WPAFB static test first failure of airplane, 1950 through 1976.

Percent Ultimate Load	Number of Failures		Cumulative Number of Failures		Cumulative Percent of Failures	
	Low	High	Low	High	Low	High
40	2	1	2	1	9.1	4.5
60	3	4	5	5	22.7	22.7
65	1	0	6	5	27.3	22.7
67	1	1	7	6	31.8	27.3
70	2	1	9	7	40.9	31.8
75	0	2	9	9	40.9	40.9
76	1	1	10	10	45.5	45.5
80	4	1	14	11	63.6	50.0
85	0	1	14	12	63.6	54.5
90	3	5	17	17	77.3	77.3
95	2	2	19	19	86.4	86.4
<100	-	-	19	19	86.4	86.4
100	3(1)	3(1)	22	22	100.0	100.0

NOTE: Landing gear, fuselage, wing, horizontal tail, and vertical tail test results used.
(1). No failure.

TABLE XXI. WPAFB static tests first failure of control system structural components.

Percent Ultimate Load	Number of Failures		Cumulative Number of Failures		Cumulative Percent of Failures	
	Low	High	Low	High	Low	High
20	1	1	1	1	6.7	6.7
40	1	0	2	1	13.3	6.7
47	1	1	3	2	20.0	13.3
50	1	2	4	4	26.7	26.7
60	3	2	7	6	46.7	40.0
67	1	2	8	8	53.3	53.3
100	7(1)	7(1)	15	15	100.0	100.0

NOTE: Number is percent of Design Ultimate Load (DUL).
(1). No failure.

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TABLE XXII. WPAFB static tests first failure of secondary structure (other).

Percent Ultimate Load	Number of Failures		Cumulative Number of Failures		Cumulative Percent of Failures	
	Low	High	Low	High	Low	High
30	1	1	1	1	4.8	4.8
50	2	2	3	3	14.3	14.3
60	4	4	7	7	33.3	33.3
67	2	2	9	9	42.9	42.9
70	1	1	10	10	47.6	47.6
80	3	3	13	13	61.9	61.9
85	1	0	14	13	66.7	61.9
90	1	2	15	15	71.4	71.4
95	1	1	16	16	76.2	76.2
100	5(1)	5(1)	21	21	100.0	100.0

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TABLE XXX. Initial flaw assumptions

Category	Critical Detail	Initial Flaw Assumption (1) (2)
Metallic Structure		
Slow Crack Growth and Fail Safe Primary Element	Hole, Cutouts, etc. Other Welds Embedded Defects	For thickness ≤ .05", .05" long through thickness flaw For thickness ≥.05", .05" radius corner flaw For thickness ≤ .125", .25" long through thickness flaw For thickness > .125", .125" deep x .25" long surface flaw TBD TBD
Metallic Structure		
Fail-safe Adjacent Structure Multiple Load Path Dependent	Holes, cutouts, etc. Other	For thickness ≤.05", .05" long through thickness flaw + Δ a For thickness > .05", .05" radius corner flaw + Δ a For thickness ≤.125", .25" long through thickness flaw + Δ a For thickness > .125", .125" deep x .25" long surface flaw + Δ a
Multiple Load Path Independent and Crack Arrest	Holes, cutouts, etc. Other	.005" radius corner flaw + Δ a .01" deep x .02" long surface flaw + Δ a
Other Material Systems (3)	TBD	TBD

(1) Flaw oriented in most critical direction.
(2) Δ a is the incremental growth of the indicated flaw prior to primary element failure.
(3) Including organic and metal matrix composites.

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TABLE XXXI. Continuing damage assumption for situation where initial flaw growth terminate prior to catastrophic failure (1)

Initial Flaw or Primary Damage Termination Site	Continuing Damage Site	Continuing Damage Assumption (2) (3)
Fastener hole, Cutout, etc.	Diametrically opposite side of hole where damage terminated	.005" radius corner flaw + Δ a
Other	Diametrically opposite side of hole where damage initiated	.005" radius corner flaw + Δ a
Complete element or member failure	Critical location in adjacent structure	.005" radius corner flaw + Δ a or .01" deep x .02" long surface flaw(4) + Δ a

(1) Applicable to metallic structures only, requirements for other material systems are TBD.
(2) Flaw oriented in most criticial direction.
(3) Δ a is the incremental growth of the indicated flaw prior to initial damage termination.
(4) Other flaw shapes and sizes can be assumed based on an equivalent stress intensity.

TABLE XXXII. In-service inspection initial flaw assumptions.

Accessibility	Inspection Method	Initial Flaw Assumption (1) (2)
Off-Aircraft or On-Aircraft with Fastener Removal	Same as initial	Same as initial
On-Aircraft without Fastener removal but Accessible	Penetrant, Mag Particle, Ultrasonic, Eddy Current	For thickness $\leq$ .25", .25" long through thickness flaw at holes (1) For thickness $\leq$ .25", .50" long through thickness flaw at other location (1) For thickness > .25", .25" radius corner crack at holes (3) For thickness > .25", .25" deep x .50" long surface flaw at other locations (1) For thickness .25", 2.0" through thickness flaw (3)
On-Aircraft with restricted Accessibility	Visual	For slow crack growth structure, non-inspectable For fail-safe structure, primary load path failed

(1) May be superceded by special inspection capability demonstration.
(2) Applicable to metallic structures, only, requirments for other matierial systems are TBD.
(3) Flaw size indicated is uncovered crack length.

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TABLE XXXIII. Minimum periods of unrepaired service usage for in-service inspectable structures

Inspectability	P_{XX} per 3.12.1	Minimum Period of Unrepaired Service Usage
In-Flight Evident	P_{FE}	Return to Base
Ground Evident	P_{GE}	Two Flights of Most Damaging Design Mission
Walkaround	P_{WV}	5 x Inspection Interval
Special Visual	P_{SV}	2 x Inspection Interval
Depot or Base Level	P_{DM}	2 x Inspection Interval

TABLE XXXIV. Subsequent in-service inspection intervals for fail-safe structures.

Primary Element Degree of Inspectability	P_{XX} per 3.12.2	Subsequent Inspection Intervals
In-Flight Evident	P_{FE}	Each Flight(1)
Ground Evident	P_{GE}	Two Flights(1)
Walkaround	P_{WV}	Ten Flights(1)
Special Visual	P_{SV}	One Year
Depot or Base Level	P_{DM}	(2)

(1) Most damaging design mission.
(2) One half of the remaining time to failure of the adjacent structure from the flaw size specified in 3.12.1 for adjacent load paths at the time of primary element failure or, if the adjacent structure is inspected, one half of the remaining time to failure of the adjacent structure from in-service inspection flaw size for the adjacent sturcture as specified in 3.12.1 (see Figure 30). In either case, the primary element is assumed to be failed. As indicated in 3.12.1, appropriate damage sizes and types must be established for non-metallic structure.

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TABLE XXXV Data Requirements (Typical).

(The following Data Item Descriptions have been used in past procurements.)

Item No.	Paragraph	Data Requirement	Availability Submittal Date	Submittal Category	DID or Format Ref.
1	3.1/4.1 3.2/4.2 3.3/4.3/*	Detailed Structural Criteria Report	30 days before preliminary design review (PDR)	III	DI-S-30587
2	3.2.5/4.2.5 /*	Weight, Balance, and Inertia Data	Throughout program, updates as appropriate	III	DI-S-3584
3	3.4/4.4/*	Load Analysis Reports	45 days before critical design review (CDR)	III	DI-S-30588
4	4.4/*	Instrumentation and Calibration Report	30 days prior to beginning of test	III	DI-T-30728
5	4.4/*	Flight Loads Survey Data Report	60 days after 80% survey initial phase and 45 days after 100% survey for final phase	III	DI-T-30729
6	4.4/*	Dynamic Response Test Report	90 days after completion of tests	III	DI-T-30730
7	3.5/4.5 3.6/4.6/*	Vibration and Aeroacoustic Analyses	90 days prior to critical design review (CDR)	III	DI-S-30581
8	4.5/4.6/*	Vibration and Noise Test Reports	30 days after each test completion	III	DI-T-30735
9	3.7/4.7/*	Flutter Analysis Report	45 days prior to critical design review (CDR)	III	DI-MISC-81390
10	4.7/*	Flutter Model Test Report	90 days after test completion	III	DI-MISC-81389
11	4.7/*	Airframe Rigidity Test Report	90 days after test completion	III	DI-MISC-81387
12	4.7/*	Flight Flutter Test Report	90 days after test completion	III	DI-MISC-81388

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TABLE XXXV Data Requirements (Typical).

(The following Data Item Descriptions have been used in past procurements.)

Item No.	Paragraph	Data Requirement	Availability Submittal Date	Submittal Category	DID or Format Ref.
13	3.8/4.8/*	Nuclear Survivability Design Analysis and Trade Study Report	45 days before critical design review (CDR)	III	DI-S-30554
14	3.9/4.9/*	Vulnerability Assessment Report	45 days before critical design review (CDR)	II	DI-R-30513
15	3/10/4.10/*	Structural Description Report	45 days before critical design review (CDR)	II	DI-S-3595
16	3.10.1/ 4.10.1/ 3.10.2/ 4.10.2	Materials and Processes Characterization Report	90 days after contract	II	DI-E-3130 DI-E-3131
17	3.10.3/ 4.10.3/ 3.10.4/ 4.10.4/*	Internal Loads and Static Strength Analysis Report	30 days after completion of fabrication of the first component for which analysis is made	III	DI-S-30658
18	4.10.5/*	Static Design Development, and/or Preproduction Component Design Verification Test Report	30 days after completion of tests	II	DI-T-30742
19	4.10.5/*	Static Test Progress Reports	Every 30 days after start of testing	I	DI-T-30740
20	4.10.5/*	Static Test Procedures and Data Report	30 days prior to test	II	DI-T-30740
21	4.10.5/*	Final Static Test Report	90 days after completion of each test	III	DI-T-30740

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(The following Data Item Descriptions have been used in past procurements.)

Item No.	Paragraph	Data Requirement	Availability Submittal Date	Submittal Category	DID or Format Ref.
22	3.10/4.10/ *	Strength Summary and Operating Restriction Report	60 days prior to first flight	III	DI-S-3589
23	3.11/4.11/ *	Durability Analysis Reports	45 days prior to critical design review (CDR) - Updates per DID(7)	III	DI-T-30722
24	3.11.2/ 4.11.2	Corrosion Prevention and Control Documents (Including plans finish specs and technical orders)	45 days prior to critical design review (CDR)	III	DI-S-3598
25	4.11/*	Durability Test Results Reports	90 days after completion of each test	III	DI-T-30726
26	3.12/4.12/ *	Damage Tolerance Analysis Report	45 days prior to critical design review (CDR)	III	DI-T-30724
27	4.12	Damage Tolerance Test Results Report	90 days after completion of each test	III	DI-T-30725
28	3.15/4.15	Service Life Monitoring Report	60 days prior to delivery of first production aircraft	III	DI-S-3588/M or new no.
29	3.15/4.15	Loads Environment Spectra Survey Data Report	Periodically (Monthly or Quarterly)	II	DI-S-30584
30	3.15/4.15	Force Structural Maintenance Data Requirements Methodology Report	60 days prior to delivery of first production aircraft	III	DI-S-30584

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TABLE XXXV Data Requirements (Typical).

(The following Data Item Descriptions have been used in past procurements.)

Item No.	Paragraph	Data Requirement	Availability Submittal Date	Submittal Category	DID or Format Ref.
31	3.15/4.15	Individual Aircraft Tracking (IAT) Data Report	Periodically (Monthly or Quarterly)	II	DI-T-30731
32	4./*	Design Development Test Reports	90 days after completion of each test	III	DI-T-30736
33	3./4./*	Structural Redesign Report	60 days prior to production	III	DI-S-30590
34	1.2.1/3.10.8/ 4.10.8/*	Class II Modification Documentation	In accordance with the DIDs reference in DI-E-3115	In accord-ance with the DIDs referenced in DI-E-3115	DI-E-3115

* and subparagraphs

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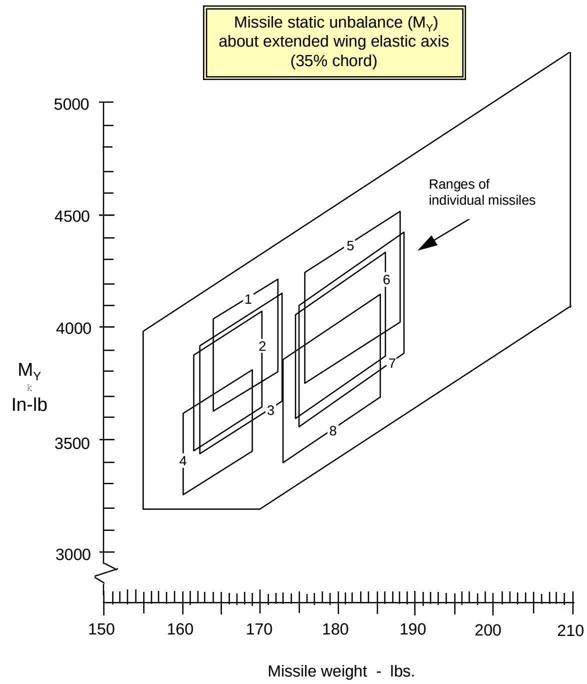

FIGURE 1. Air-to-air missile weight - static unbalance envelope for a fighter.

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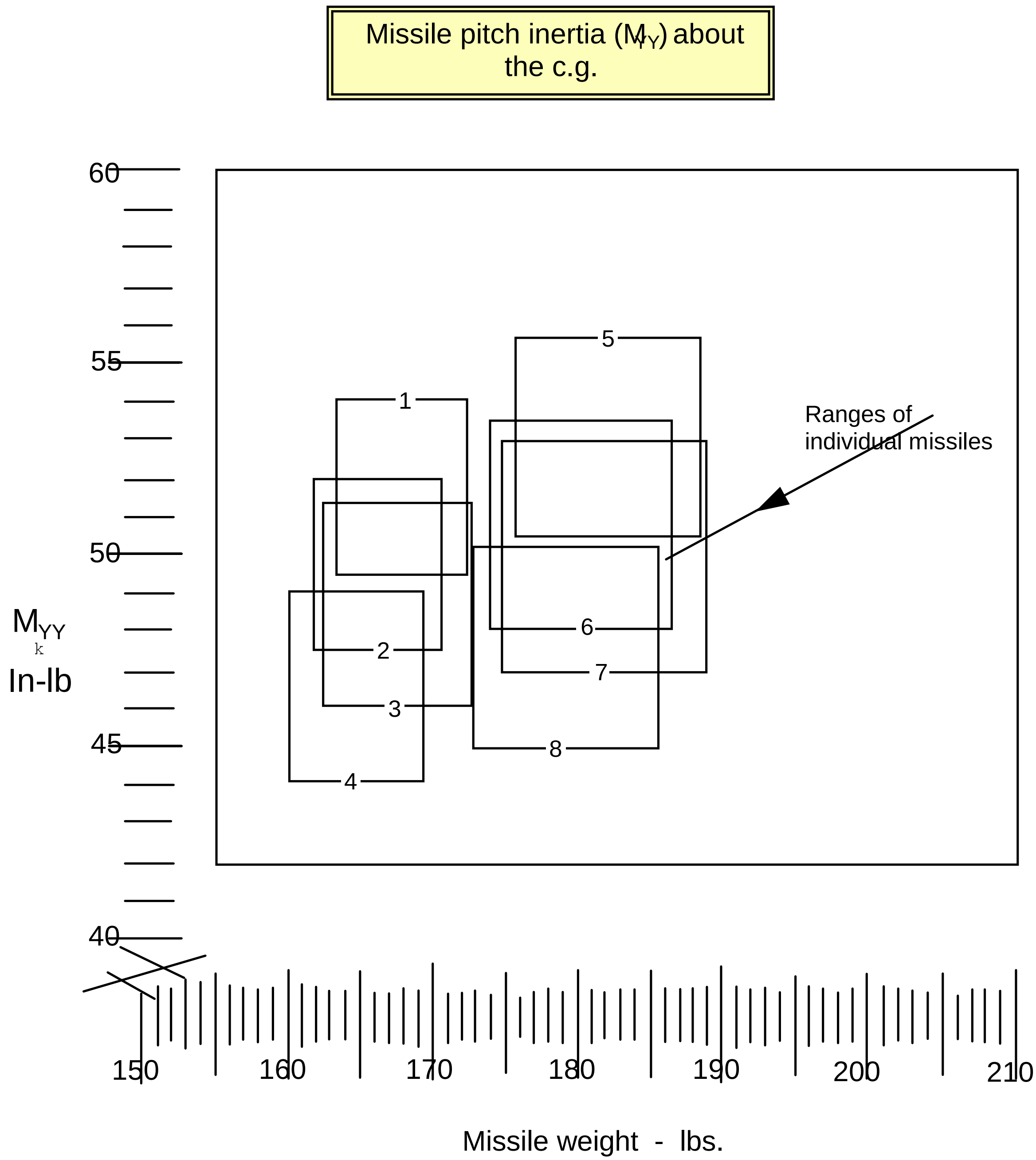

FIGURE 2. Air-to-air missile weight - inertia envelope for a fighter.

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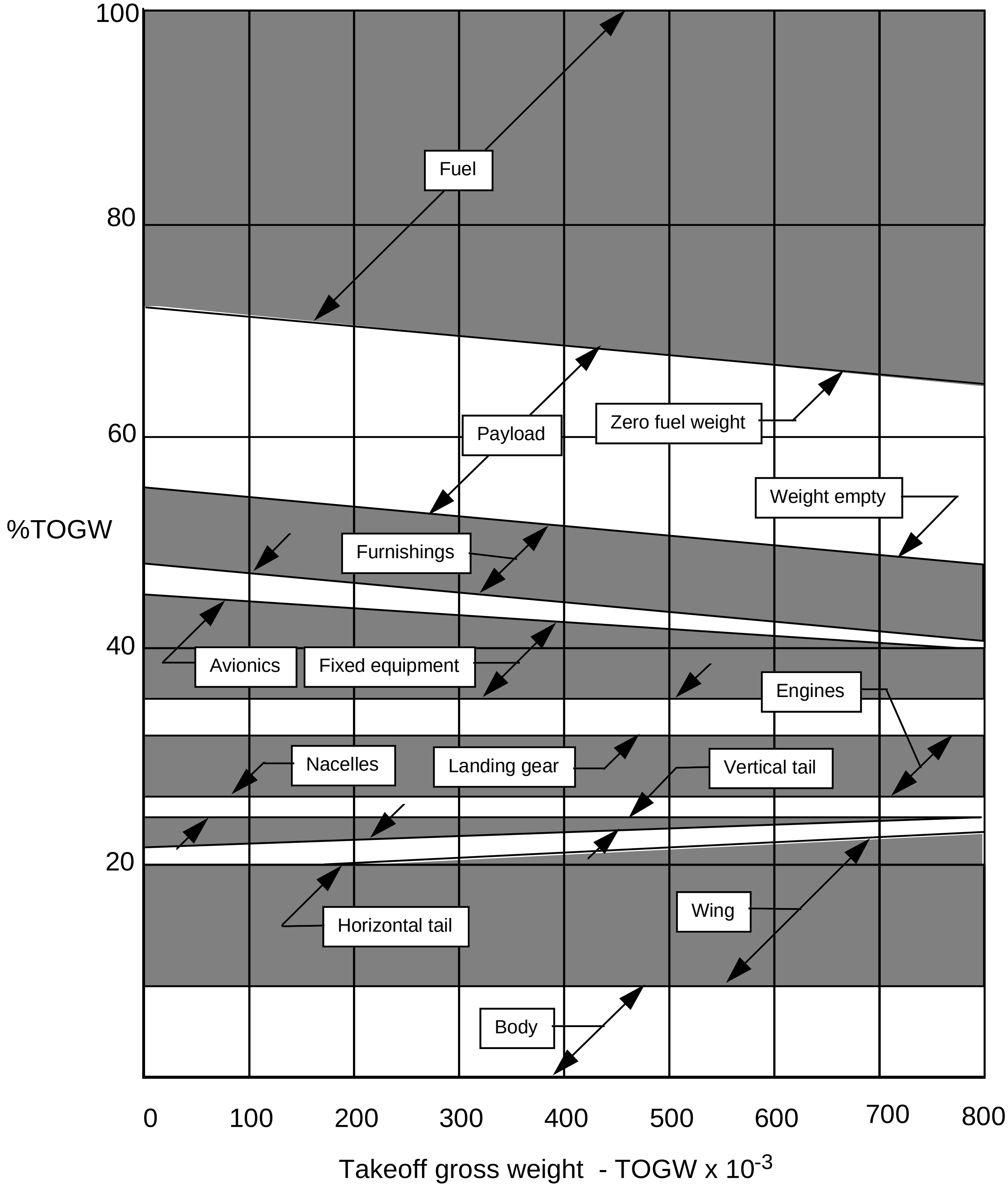

FIGURE 3. Bomber and cargo item weight percentages.

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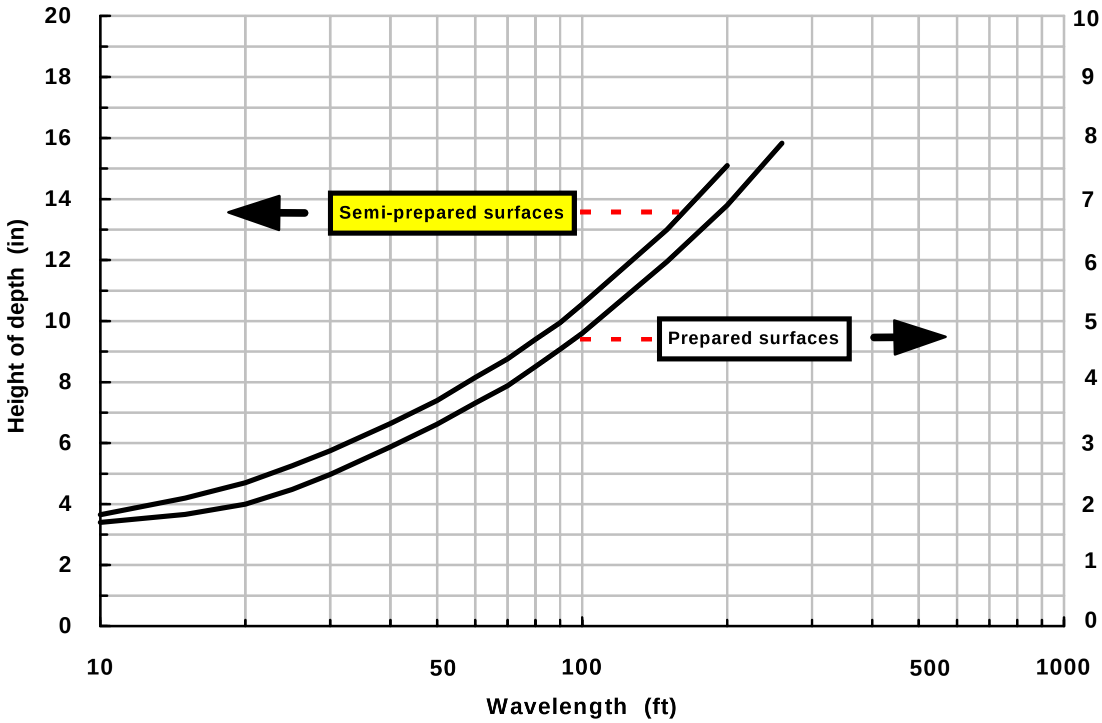

FIGURE 4. Discrete (1-cos) bumps and (cos -1) dips for slow speeds up to 50 knots -- single and double excitations.

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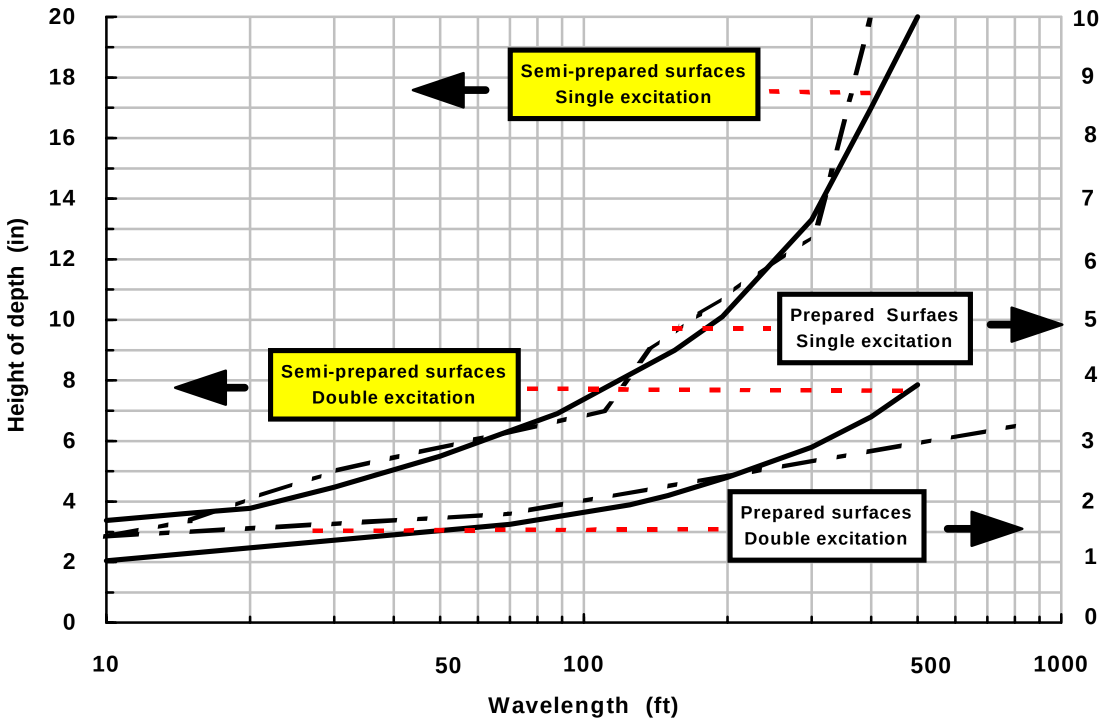

FIGURE 5. Discrete (1-cos) bumps and (cos -1) dips for high speeds above 50 knots -- single and double excitations.

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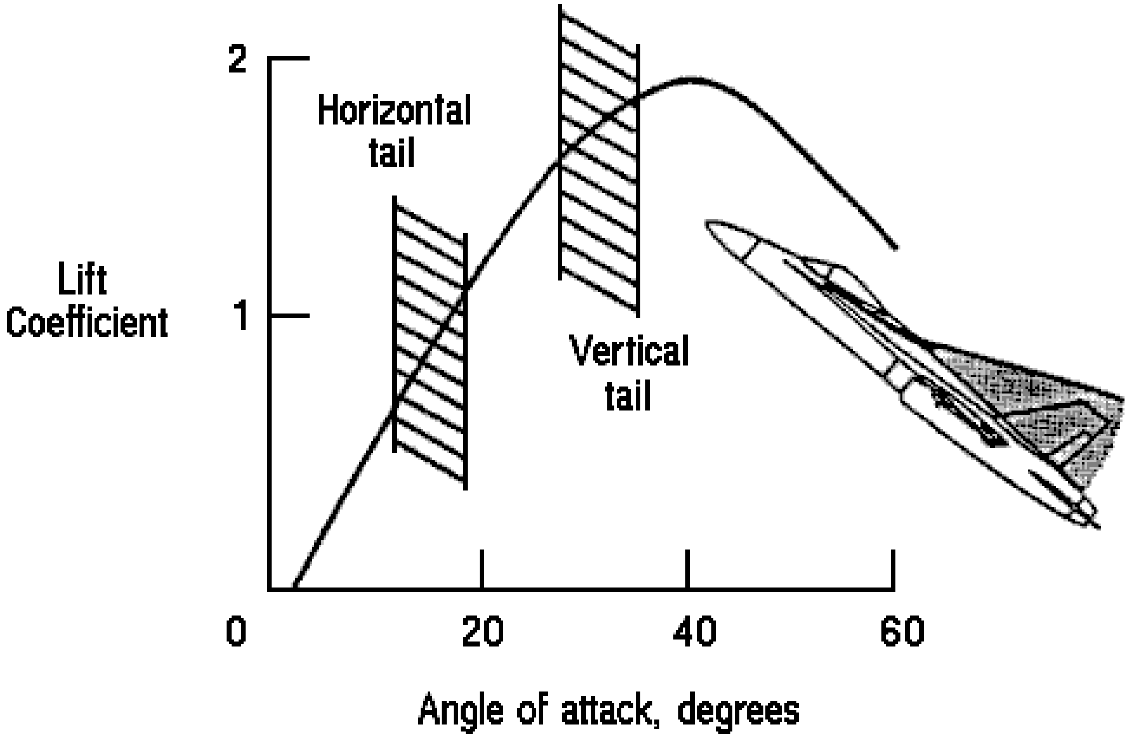

FIGURE 6. Regions of vortex-induced buffet loads (Edwards and Malone).

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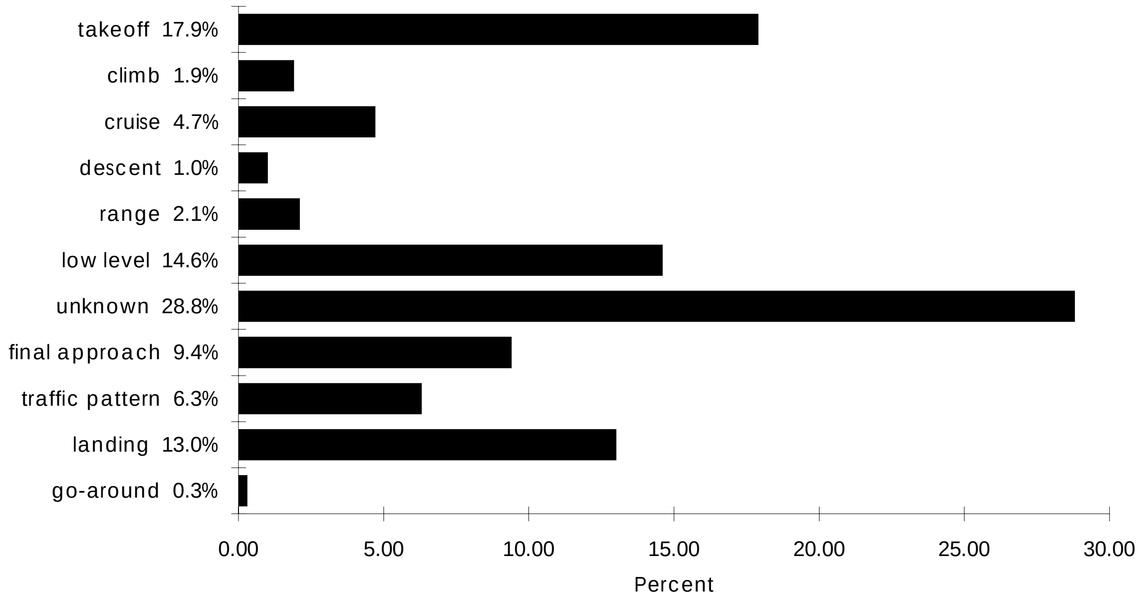

FIGURE 7. Bird strikes by phase of flight.

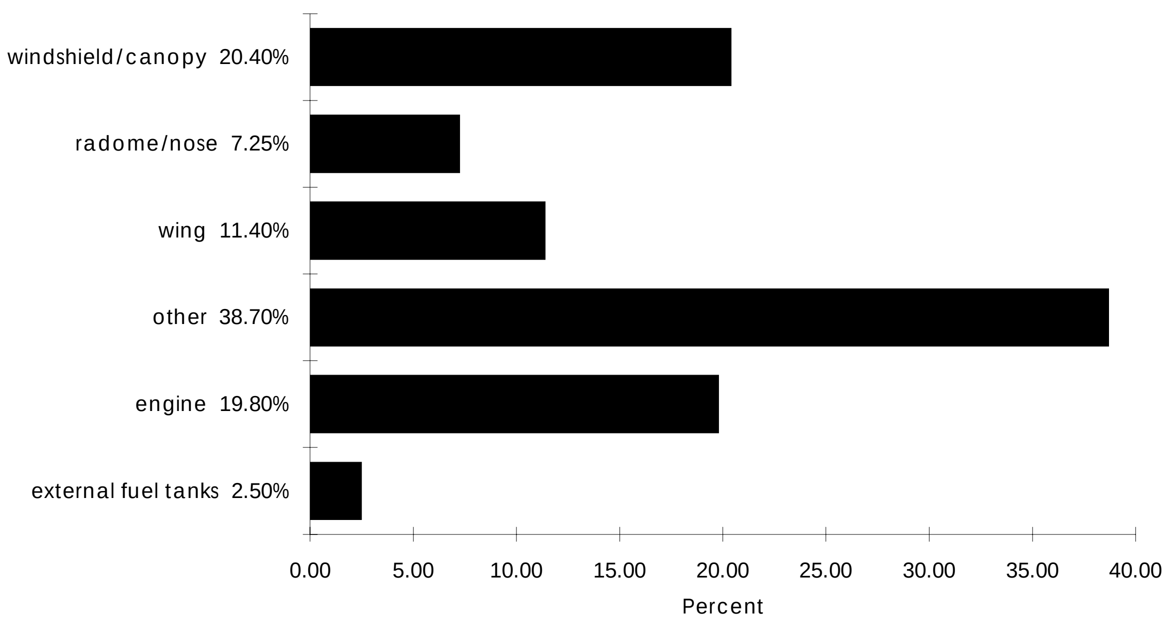

FIGURE 8. Bird strike by impact area on airframe.

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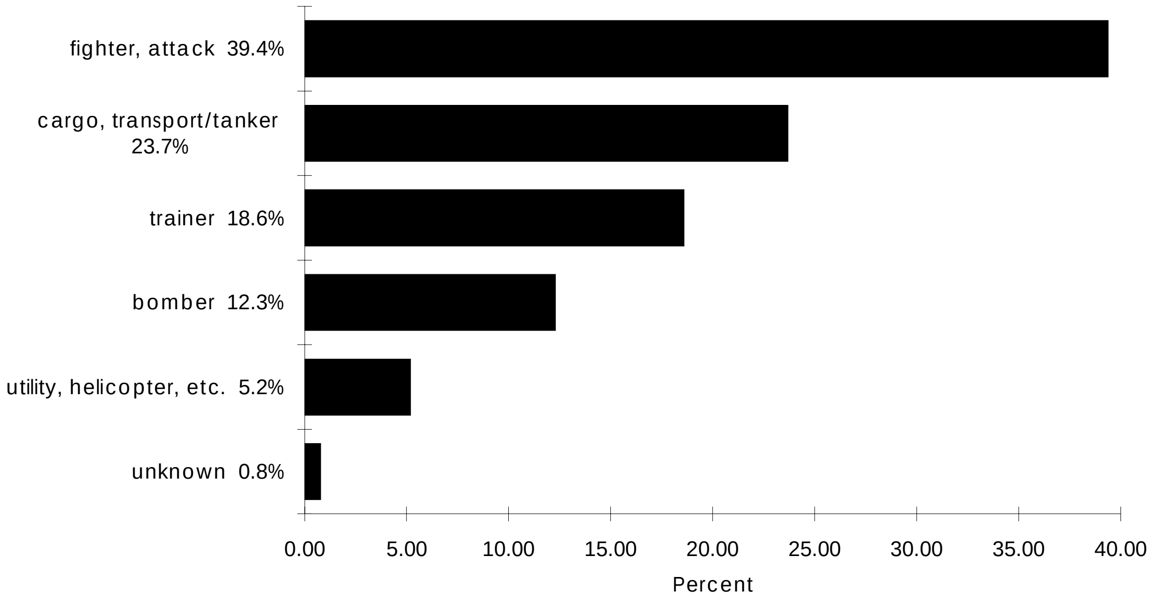

FIGURE 9. Bird strike by type of aircraft.

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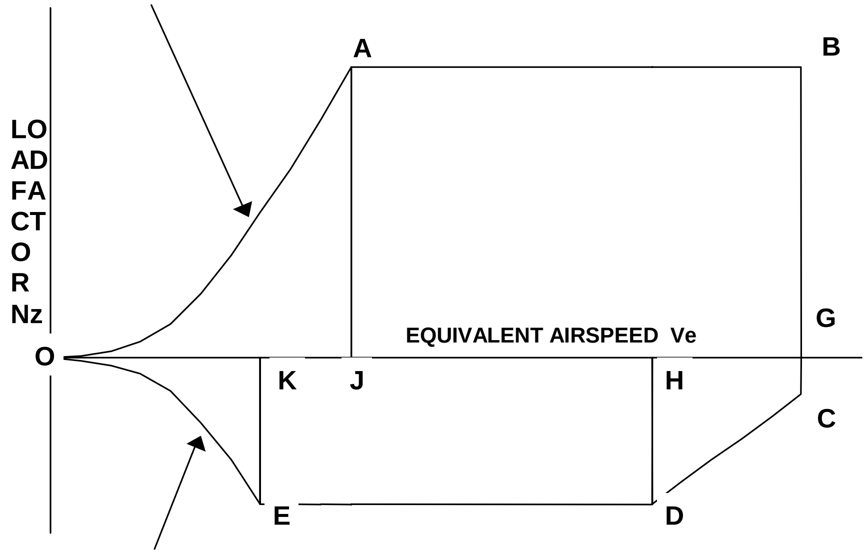
$$n_z = k \frac{\rho_o V_e^2}{2W/S} C_{N_{amax}}$$



$$n_z = \frac{\rho_o V_e^2}{2W/S} C_{N_{amin}}$$

NOTES:

1. JA = GB = Value specified in paragraph 3.2.9
2. GC = Value specified in paragraph 3.2.9
3. HD = KE = Value specified in paragraph 3.2.9
4. OH = V_H as specified in paragraph 3.2.7
5. OG = V_D or V_L as specified in paragraph 3.2.7
6. k = ___________________________.

Because k varies greatly depending on the configuration it should be defined keeping in mind the particular configuration under consideration. Also, k may be determined from applicable wind tunnel and flight test data acceptable to the acquisition activity. This determination shall include consideration of abruptness of the maneuver, control surface limitations, Mach number, thrust, center-of-gravity position, external stores configuration, and other effects which can be shown to have a significant bearing on the maximum attainable airplane normal force coefficient. Previous definitions of k include:

$$\underline{k} = 1.25 \text{ for } M \leq 0.6$$
$$\underline{k} = 1.0 \text{ for } M \geq 1.0$$
$$\underline{k} = 1.625 - 0.625M \text{ for } 0.6 < M < 1.0$$

where M is the Mach number corresponding to the speed being considered.

FIGURE 10. V-n diagram for symmetrical flight.

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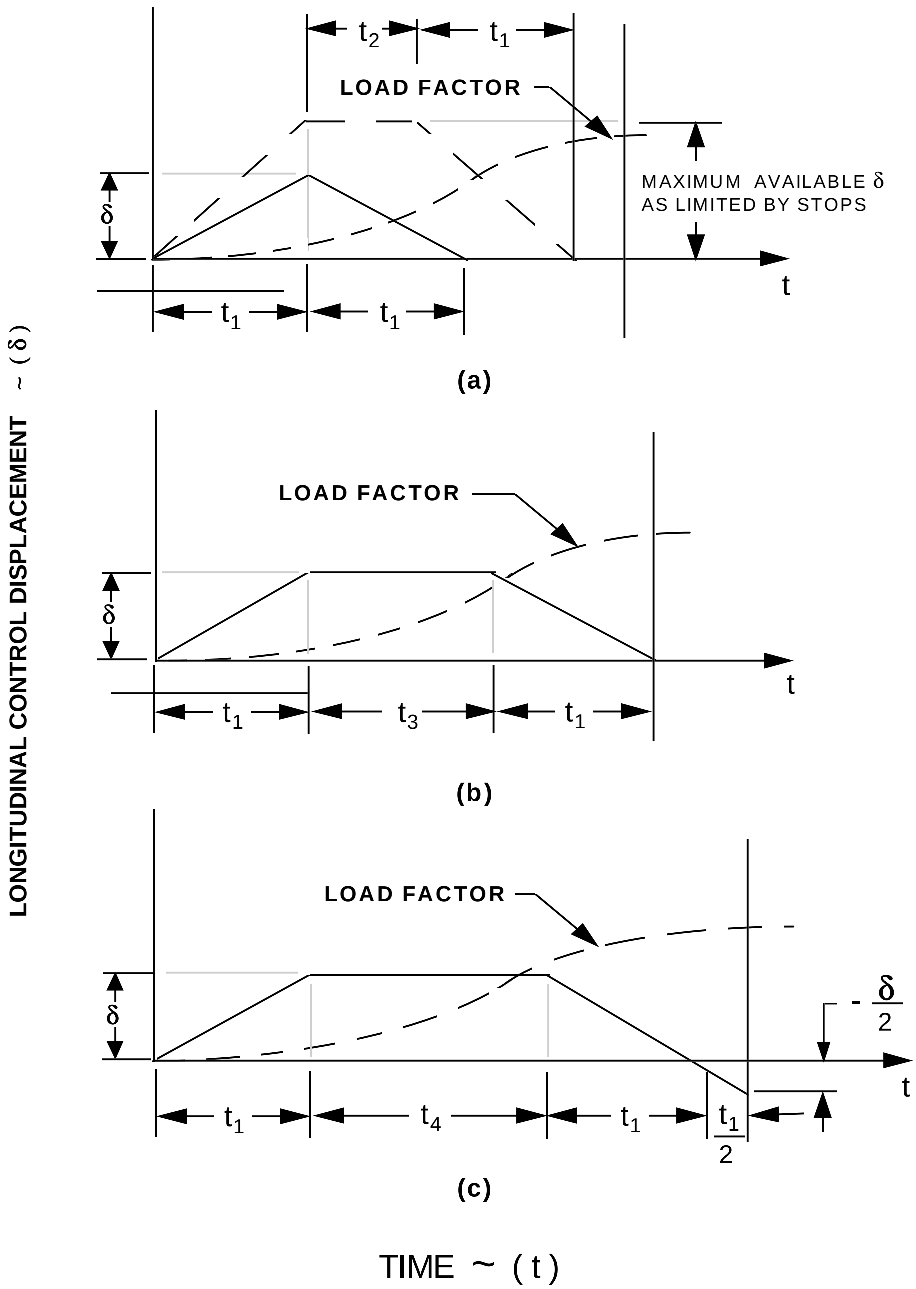

FIGURE 11. Cockpit longitudinal control displacement - time diagram.

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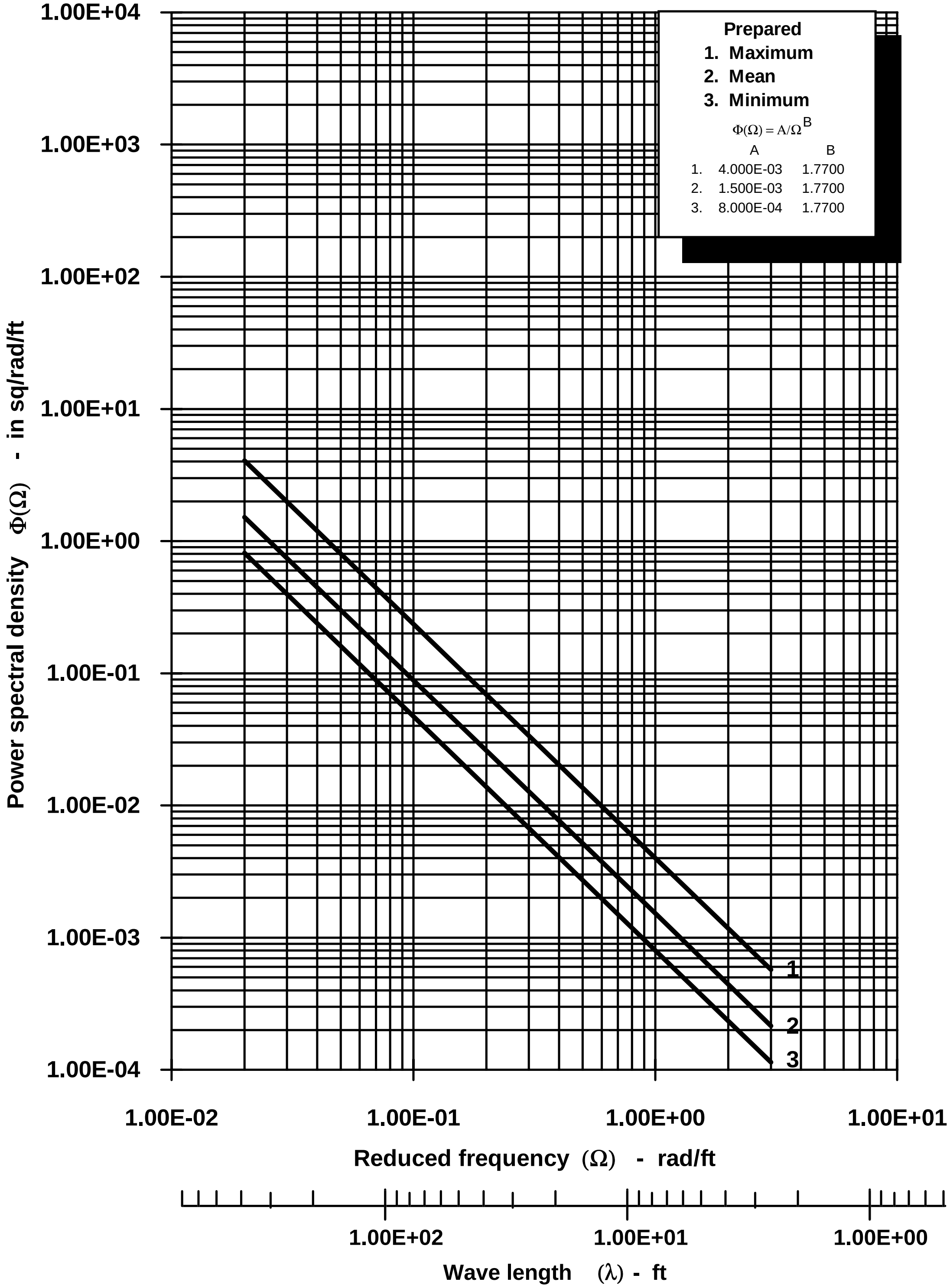

FIGURE 12. Roughness levels for prepared airfields.

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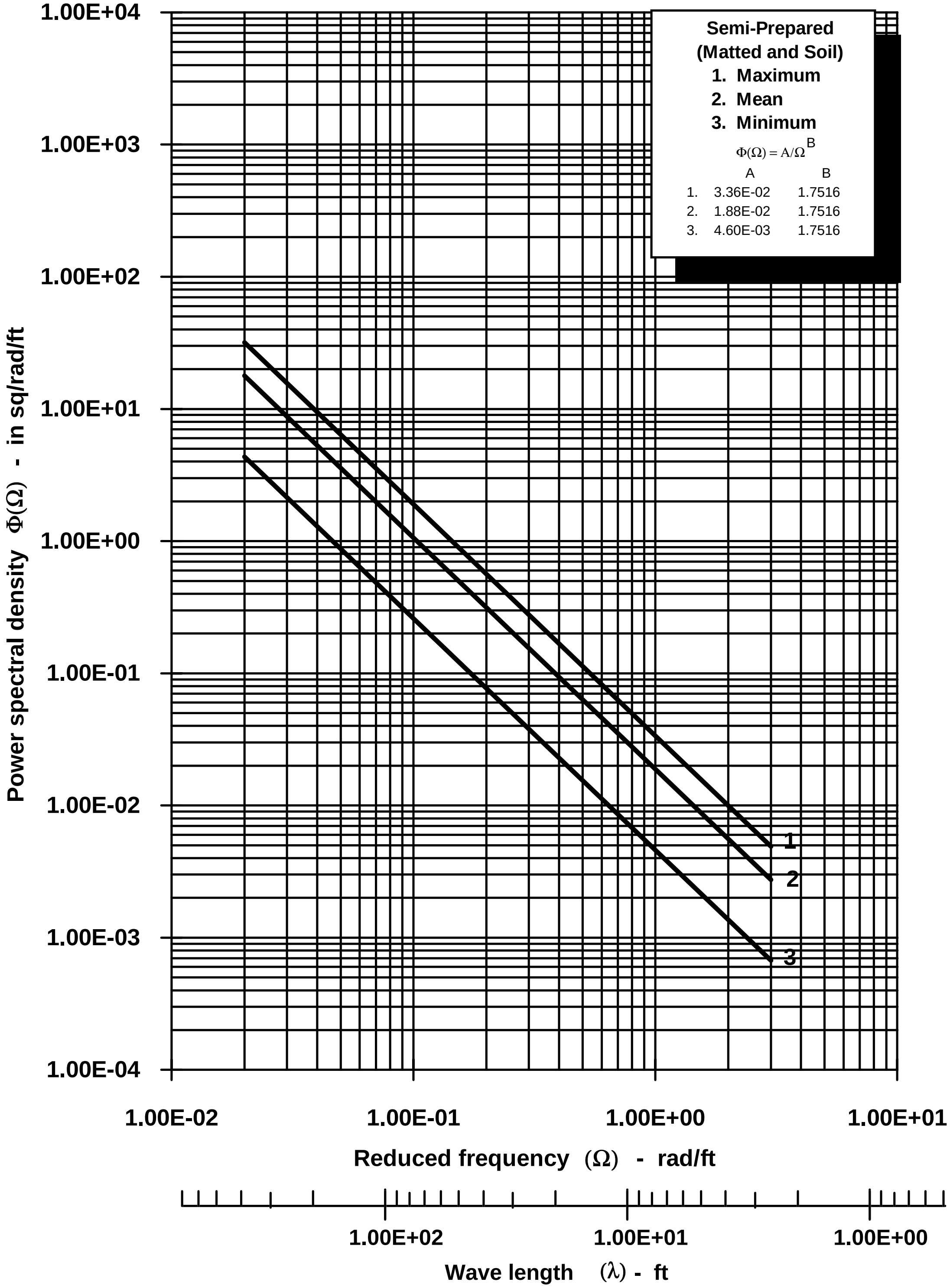

FIGURE 13. Roughness levels for semi-prepared airfields.

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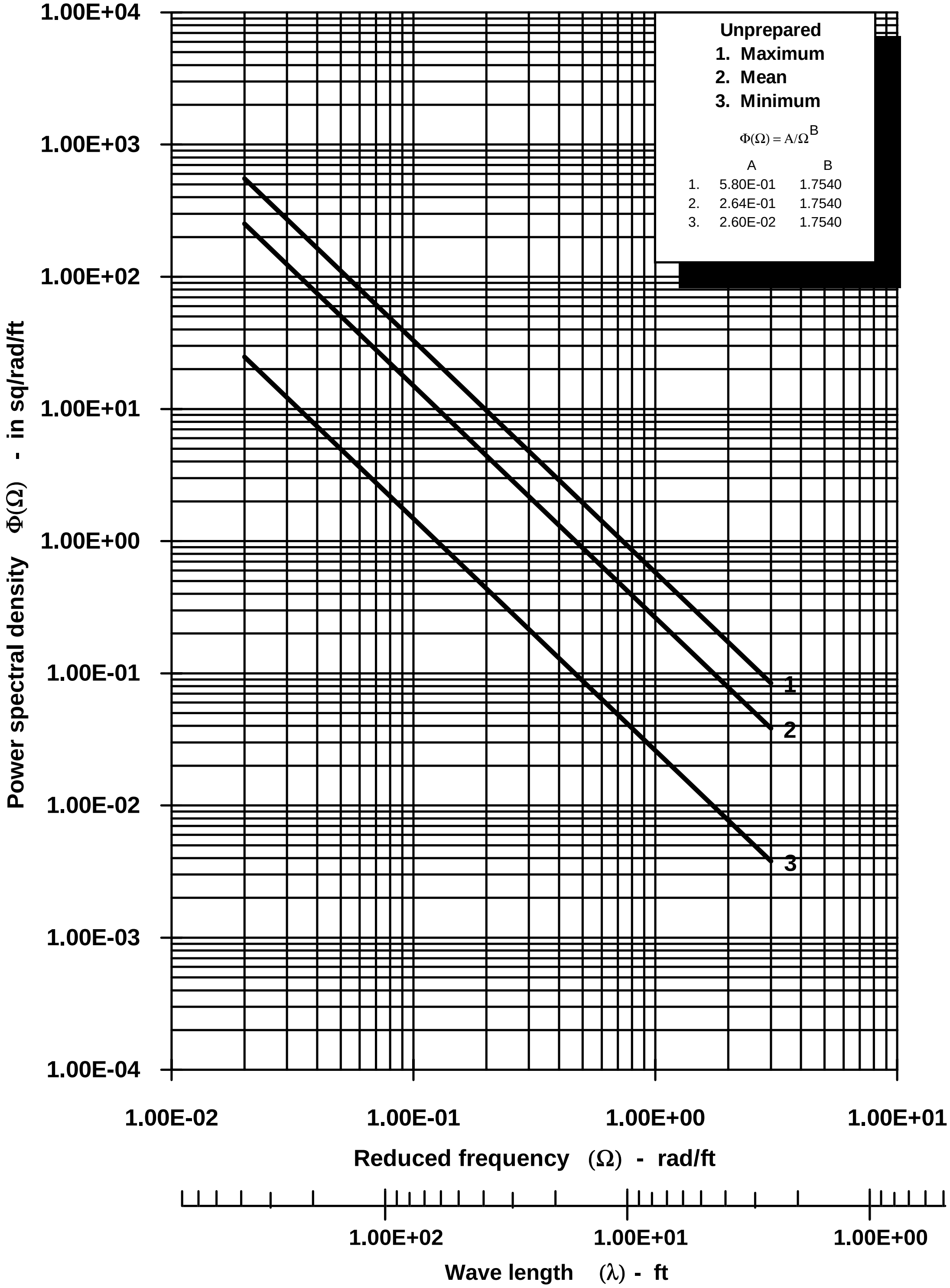

FIGURE 14. Roughness levels for unprepared airfields[(1)].

(1). This figure shall not be used for design unless specified by the procuring activity.

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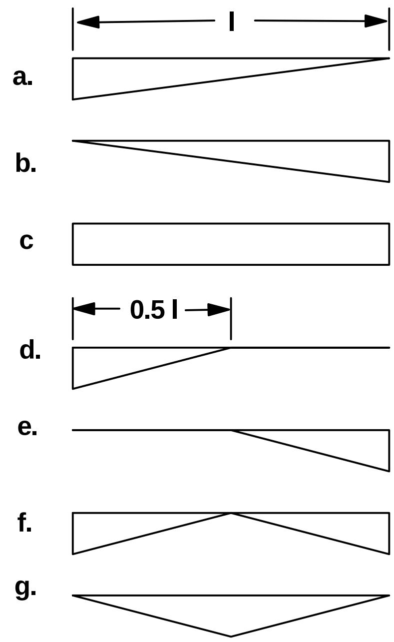

FIGURE 15. Ski load distributions.

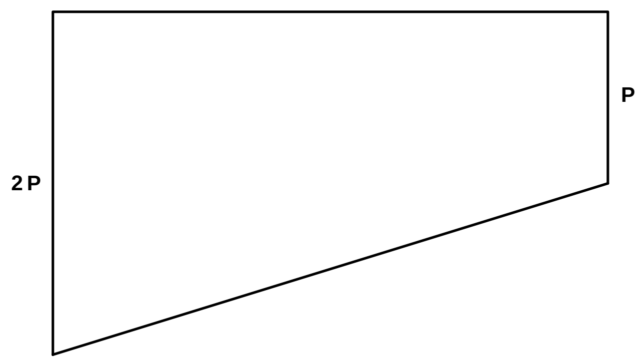

FIGURE 16. Treadwise distribution.

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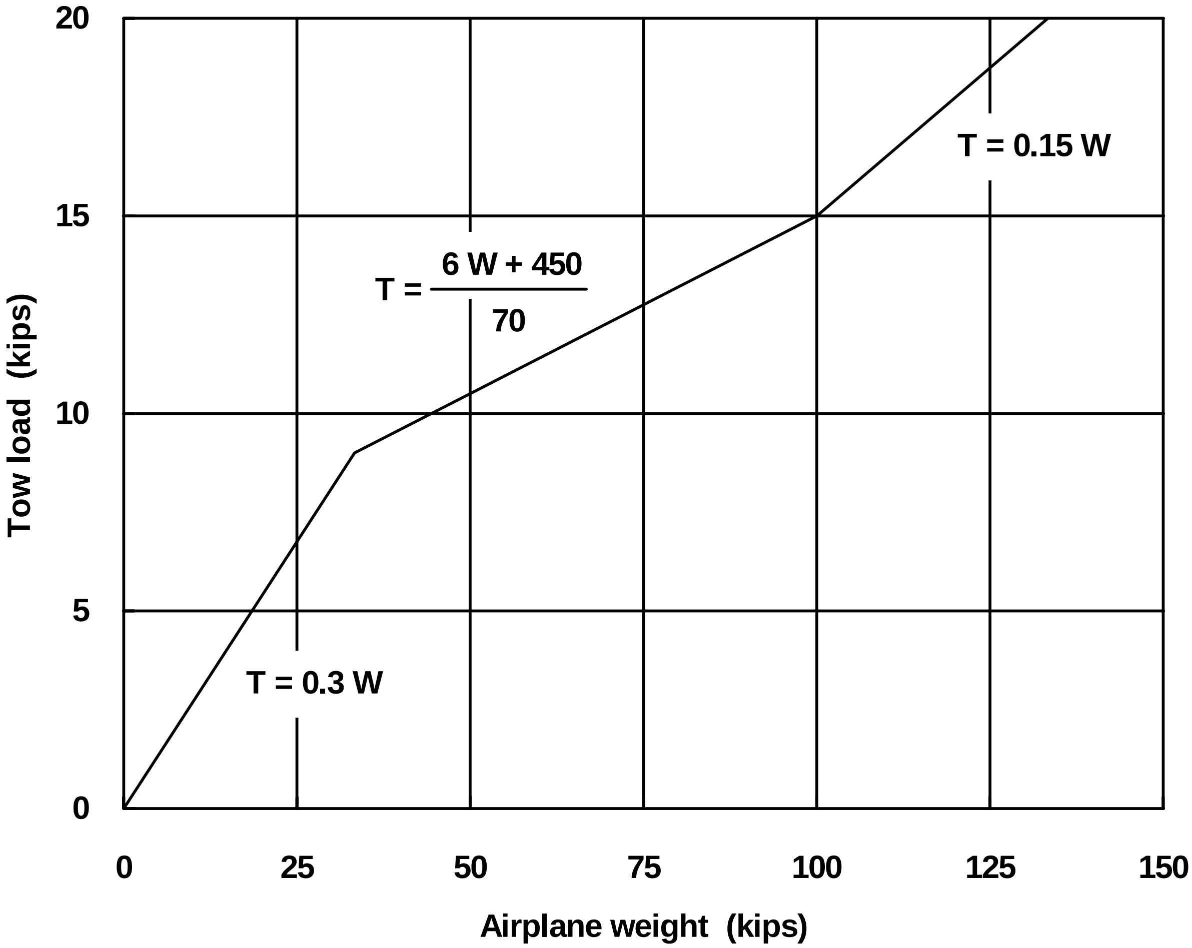

FIGURE 17. Tow loads

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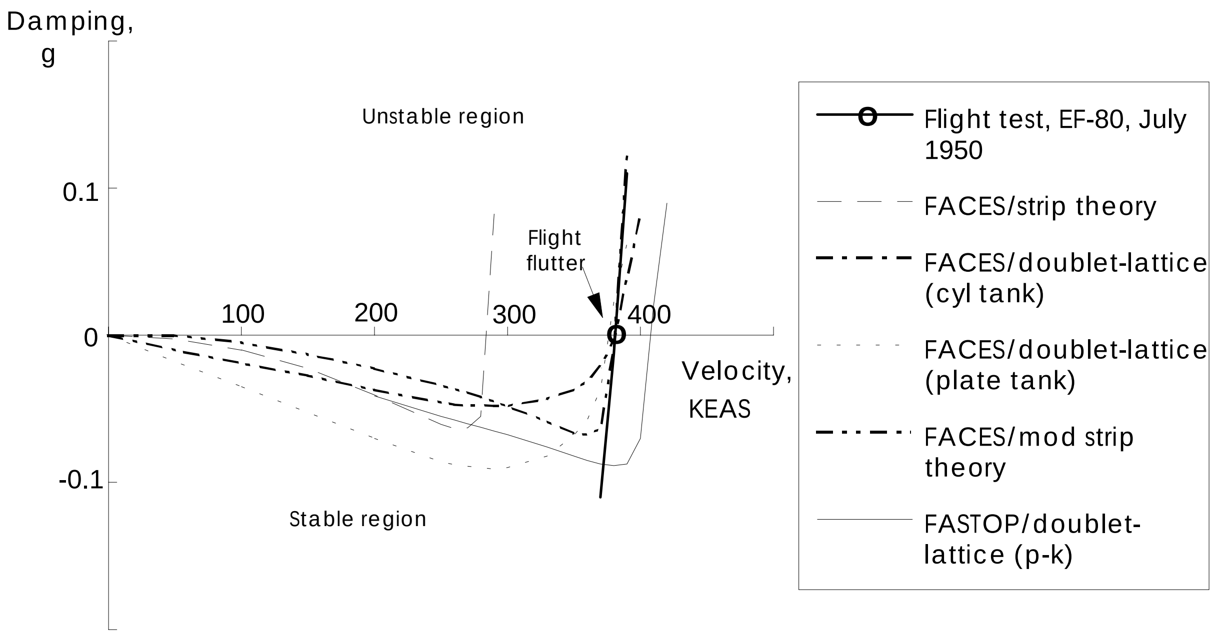

FIGURE 18. Damping versus velocity, wing with tip tank and fin.

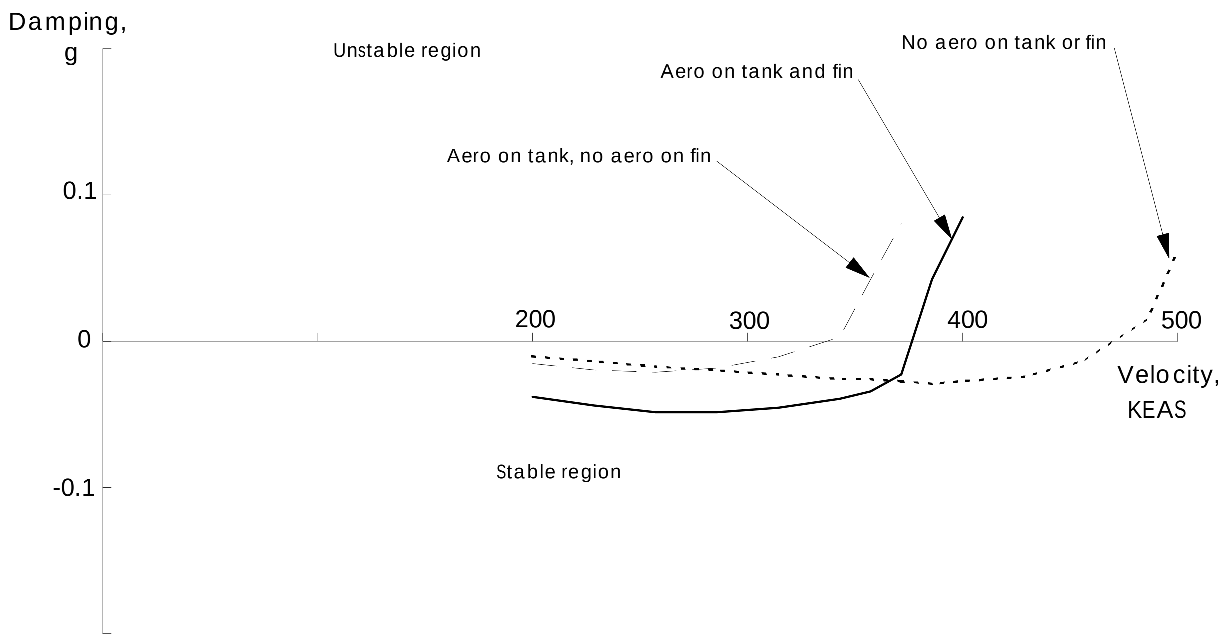

FIGURE 19. Effect of tip tank and fin aerodynamics on damping versus velocity, FACES/doublet-lattice (cylindrical tank).

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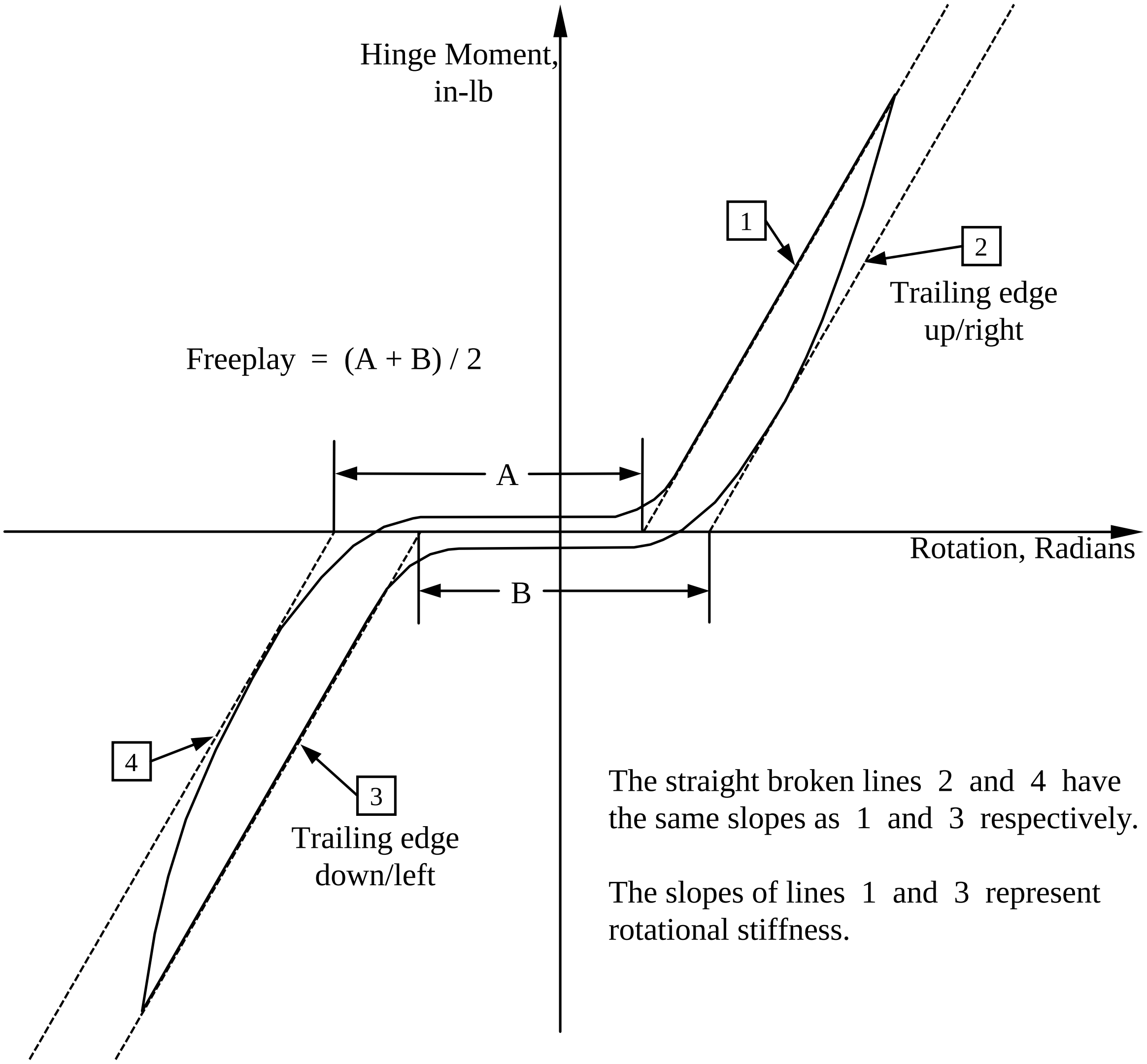

FIGURE 20. Load-deflection hysteresis diagram.

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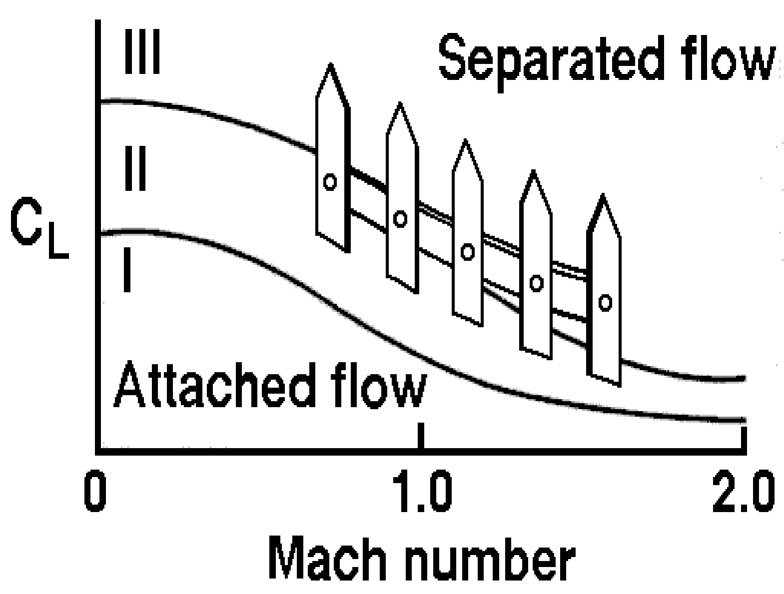

FIGURE 21. Characteristics of attached and separated flow for complete aircraft (Edwards and Malone).

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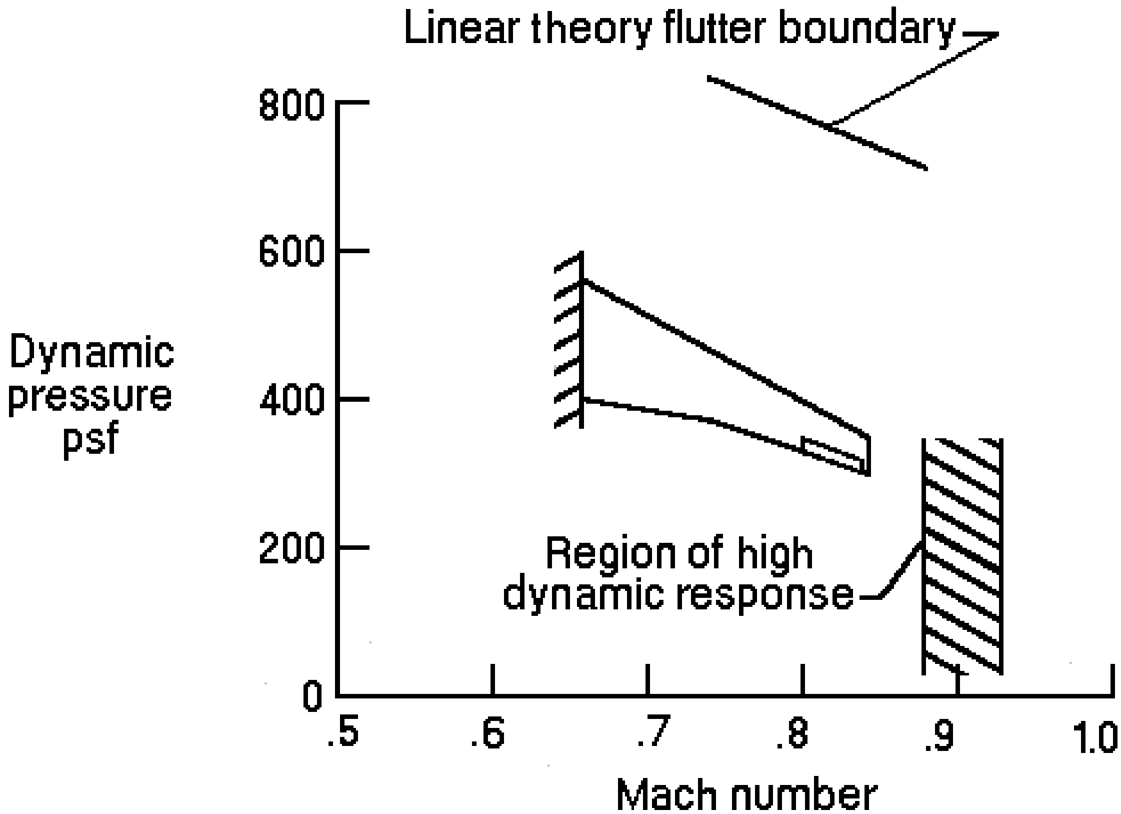

FIGURE 22. Region of high dynamic response encountered during test of a flexible supercritical wing (Edwards and Malone).

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TABLE XXXVI. Structural Verification Matrix (Typical).

		MILESTONES								
SPEC. PARA.	**REQUIREMENT**	**CA**	**SRR**	**PDR**	**CDR**	**FF**	**FCA SVR**	**GO**	**PCA**	**PROD**
3.0	REQUIREMENTS.									
3.1	Detailed structural design requirements.		X	A		CT	FD			
3.1.1	Deterministic design criteria.		X	XA		CT	FD			
3.1.2	Probability of detrimental deformation and structural failure.			A		CT	FD			
3.1.3	Structural integrity			E				Q		
3.1.3.1	Parts classification			E				Q		
3.1.3.2	Fatigue/Fracture critical parts			E				Q		
3.1.3.3	Maintenance criticial parts			E				Q		
3.1.3.4	Mission critical parts		E					Q		
3.1.3.5	Fatigue/Fracture critical traceable parts		E					Q		
3.2	General parameters.			A		CT	FD			
3.2.1	Airframe configurations.			A		CT	FD			
3.2.2	Equipment.			A		CDT				
3.2.3	Payloads.	A	A	A	C	D	D	D	D	D
3.2.4	Weight distributions.	A	A	A	A	T	T	T	T	T
3.2.5	Weights.	XA	A	A	A	T	T	T	T	T
3.2.5.1	Operating weight.	A	A	A	A	T	T	T	T	T
3.2.5.2	Maximum zero fuel weight.	A	A	A	A	T	T	T	T	T
3.2.5.3	Minimum flight weight.	A	A	A	A	T	T	T	T	T
3.2.5.4	Basic flight design gross weight.	A	A	A	A	T	T	T	T	T
3.2.5.5	Maximum flight weight.	A	A	A	A	T	T	T	T	T
3.2.5.6	Landplane landing weight.	A	A	A	A	T	T	T	T	T
3.2.5.7	Maximum landing weight.	A	A	A	A	T	T	T	T	T
3.2.5.8	Maximum ground weight.	A	A	A	A	T	T	T	T	T
3.2.5.9	Maximum take-off weight.	A	A	A	A	T	T	T	T	T
3.2.5.10	Maximum landing gear jacking weight.	A	A	A	A	T	T	T	T	T
3.2.5.11	Maximum airframe jacking weight.	A	A	A	A	T	T	T	T	T
3.2.5.12	Hoisting weight.	A	A	A	A	T	T	T	T	T
3.2.5.13	Maximum catapult design gross weight.	A	A	A	A	T	T	T	T	T
3.2.5.14	Maximum catapult weight.	A	A	A	A	T	T	T	T	T
3.2.5.15	Primary catapult mission weight.	A	A	A	A	T	T	T	T	T
3.2.5.16	Carrier landing design gross weight.	A	A	A	A	T	T	T	T	T
3.2.5.17	Barricade design gross weight.	A	A	A	A	T	T	T	T	T
3.2.5.18	Other weight.	A	A	A	A	T	T	T	T	T

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		MILESTONES								
SPEC. PARA.	**REQUIREMENT**	**CA**	**SRR**	**PDR**	**CDR**	**FF**	**FCA SVR**	**GO**	**PCA**	**PROD**
3.2.6	The center of gravity.	A	A	A	A	T	T	T	T	T
3.2.6.1	Lateral center of gravity position.	A	A	A	A	T	T	T	T	T
3.2.7	Speeds.	X	A	A			FD			
3.2.7.1	Level flight maximum speed, V_H			A			FD			
3.2.7.2	Dive speed, V_D.			A			FD			
3.2.7.3	Limit speed, V_L.	X		A			FD			
3.2.7.4	Maneuver speed, V_A.			A			FD			
3.2.7.5	Take-off, approach, and landing limit speeds, V_{LF}.			A			FD			
3.2.7.6	Lift-off limit speeds, V_{LO}.			A			FD			
3.2.7.7	Touch-down limit speeds, V_{TD}.	X		A			FD			
3.2.7.8	Taxi limit speed, V_T.			A			FD			
3.2.7.9	Gust limit speeds, V_G.			A			FD			
3.2.7.10	Maneuver stalling speeds, V_{S1}.			A			FD			
3.2.7.11	Landing stalling speeds, V_{SL}.			A			FD			
3.2.7.12	System failure limit speeds, V_{SF}.			A			FD			
3.2.7.13	Shipboard recovery speed, V_{TDC}.			A			FD			
3.2.7.14	Shipboard engaging speed, V_E.			A			FD			
3.2.7.15	Shipboard launch end speed, V_C.			A			FD			
3.2.7.16	Maximum brake speed, V_{HD}.			A			FD			
3.2.7.17	Emergency jettison speeds.			A			FD			
3.2.7.18	Selective jettison speeds.			A			FD			
3.2.7.19	Store employment speeds.			A			FD			
3.2.7.20	Other speeds.			A			FD			
3.2.8	Altitudes.			A			FD			
3.2.8.1	Maximum flight altitude.			A			FD			
3.2.8.2	Maneuver altitude.			A			FD			
3.2.8.3	Maximum ground altitude.			A			FD			
3.2.9	Flight load factors.			A			FD			
3.2.9.1	Basic flight design gross weight load factors.			A			FD			
3.2.9.2	Maximum flight weight load factors.			A			FD			

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SPEC. PARA.	REQUIREMENT	MILESTONES								
		CA	**SRR**	**PDR**	**CDR**	**FF**	**FCA SVR**	**GO**	**PCA**	**PROD**
3.2.9.3	Take-off, approach, and landing load factors.			A			FD			
3.2.9.4	High drag load factors.			A			FD			
3.2.9.5	Air vehicle load factors after detectable system failures.			A			FD			
3.2.9.6	Other flight load factors.			A			FD			
3.2.10	Land-based and ship-based aircraft ground loading parameters.			A		CT	FD			
3.2.10.1	Landing sink speeds.			A		CT	FD			
3.2.10.2	Crosswind landings.			A		CT	FD			
3.2.10.3	Land-based landing roll, yaw, pitch attitudes, and sink speed.			A		CT	FD			
3.2.10.4	Taxi discrete bumps, dips, and obstructions.	X	A	A		CT	FD			
3.2.10.5	Jacking wind loading conditions.			A		CT	FD			
3.2.10.6	Catapult take-off.			A		CT	FD			
3.2.11	Limit loads.			A	C	DT	F			
3.2.12	Ultimate loads.			A	C	D	DT			
3.2.12.1	Shipboard landing design loads.			A		D	DT			
3.2.13	Deformations.			A	C	T	F			
3.2.14	Service life and usage.	E	X							
3.2.14.1	User identified requirements.	E	X							
3.2.14.2	Representative basing concept.	E	X							
3.2.14.3	Repeated loads sources.	E	X	A	CR		FD			
3.2.14.4	Other requirements.									
3.2.14.5	Airframe structure inspection.				A			A		
3.2.14.6	Design durability service loads/spectrum.		X	A	A			A		
3.2.14.7	Design damage tolerance service loads/spectrum.		X	A	A			A		
3.2.15	Atmosphere.			A	A			A		
3.2.16	Chemical, thermal, and climatic environments.	E	AX	AD	A			AT		
3.2.17	Power or thrust loads.	E		A	AR	F	FD			
3.2.18	Flight control and stability augmentation devices.	E	A	A	AR	F	FD			
3.2.19	Materials and processes.	E	QEX	X						
3.2.19.1	Materials.	E	QAD	RC	CQ		T			
3.2.19.2	Processes.	E	QAD	RC	CQ		T			
3.2.20	Finishes.	E	AX	RDQ	C			T		

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3.2.21	Non-structural coatings, films, and layers.	E	AX	RDQ	C			T		
3.2.22	System failures.		E	X	A	T	F			
3.2.23	Lightning strikes and electrostatic charge.		X	A	C		D			
3.2.23.1	Lightning protection.	E	X	A	C		D			
3.2.23.2	Electrostatic charge control.	E	X			D				
3.2.24	Foreign object damage (FOD).	E	X							
3.2.24.1	Bird FOD.	E	X	A	C	D	T			
3.2.24.2	Hail FOD.	E	X	A	R					
3.2.24.3	Runway, taxiway, and ramp debris FOD.	E	X	A	R					
3.2.24.4	Other FOD.	E	X	A	R					
3.2.25	Producibility	E		X	D		Q			
3.2.26	Maintainability	E		X	D		Q			
3.2.27	Supportability	E		X	D		Q			
3.2.28	Repairability	E		X	D		Q			
3.2.29	Replaceability/ interchangeability	E	X		D		Q			
3.2.30	Cost effective design	E	X		D		Q			
3.3	Design and construction parameters.	E	X							
3.3.1	Doors and panels.			E	A		D			
3.3.1.1	Access doors and components.			C	A		D			
3.3.2	Doors and ramps mechanisms of pressurized compartments.	E	X	A	C	T	T	F		
3.3.3	Ramps.	E	X	A	C	T	T	F		
3.3.3.1	Engine inlet ramps or equivalent compression surfaces.	E	X	A	C		T	F		
3.3.3.2	Cargo ramps - loading and unloading.		E	A			T			
3.3.3.3	Cargo ramps - in-flight.		E	A			T			
3.3.4	Cargo floors.		E	A			T			
3.3.5	Transparencies.		E	A	R	T	F	Q		
3.3.6	Tail bumper.		E	A			T			
3.3.7	Tail hook.		E	A			T			
3.3.8	Vents and louvers.		E	A			T			
3.3.9	Cavities.		E	E	E		E			
3.3.10	Armor		E	A	C	D	T			
3.3.11	Refueling provisions.	X	E	A		C	T	D		
3.3.12	Cables and pushrods.		E	A	C	D	T	F		
3.3.13	Airframe bearings and pulleys.		E	A		D	T			

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3.3.14	Fasteners.		E	AD	CQ			T		
3.3.15	Integral fuel tanks and lines.	E	X	A	C	T	F	D		
3.3.16	Nuclear weapons retention.	X	E	A	C	T	FD			
3.3.17	Rapid decompression.	E	X	A						
3.3.18	Design provisions for ship-based suitability.		X	EA		T	F			
3.3.18.1	Wing design provisions for ship-based suitability.		X	EA		T	F			
3.3.18.1.1	Wing folding or sweeping (ship-based aircraft)		X	EA		T	F			
3.3.18.2	Empennage design for ship-based suitability.		X	EA		T	F			
3.3.18.3	Cockpit/cabin design for ship-based suitability.		X	EA	C	T	FP			
3.3.18.4	Equipment compartment ship-based suitability requirements.		X	EA		D	FP			
3.3.18.5	Landing gear ship-based suitability requirements.	X	E	A		D	FP			
3.3.19	Repeatable release holdback bar.	X	E	A		D	FP			
3.3.20	Other design and construction parameters.		X	EA		D	F			
3.4	Structural loading conditions.		X	EA	CT		FD			
3.4.1	Flight loading conditions.		X	EA	CT		FD			
3.4.1.1	Symmetric maneuvers.		X	ERA	CT		FD			
3.4.1.2	Asymmetric maneuvers.		X	ERA	CT		FD			
3.4.1.3	Directional maneuvers.		X	ERA	CT		FD			
3.4.1.4	Evasive maneuvers.		X	ERA	CT		FD			
3.4.1.5	Other maneuvers.		X	ERA	CT		FD			
3.4.1.6	Turbulence.		X	EA	CT		FD			
3.4.1.7	Aerial refueling.		X	EA	CT		FD			
3.4.1.7.1	Tanker.		X	EA	CT		FD			
3.4.1.7.2	Receiver.		X	EA	CT		FD			
3.4.1.8	Aerial delivery.		X	EA	CT		FD			
3.4.1.9	Speed and lift control.		X	ERA	CT		FD			
3.4.1.9.1	Speed control.		X	ERA	CT		FD			
3.4.1.9.2	Lift control.		X	ERA	CT		FD			
3.4.1.10	Braking wheels in air.		X	EA	CT		FD			
3.4.1.11	Extension and retraction of landing gear.		X	EA	CT		FD			
3.4.1.12	Pressurization.		X	EA	CT		FD			
3.4.1.13	Aeroelastic deformation effects.		X	ERA	CT		FD			
3.4.1.14	Dynamic response during flight operations.		X	ERA	CT	F	FD			

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3.4.1.15	Other flight loading conditions.		X	ERA	CT	F	FD			
3.4.2	Ground loading conditions.		X	EA	CT		FD			
3.4.2.1	Taxi.		X	EA	CT		FD			
3.4.2.2	Turns.			EA	CT		FD			
3.4.2.3	Pivots.		X	EA	CT		FD			
3.4.2.4	Braking.		X	EA	CT		FD			
3.4.2.5	Take-offs.		X	EA	CT	F	FD			
3.4.2.6	Landings.		X	EA	CT	F	FD			
3.4.2.7	Dynamic response during ground/ship-based operations.		X	ERA	CT	F	FD			
3.4.2.8	Ski equipped air vehicles.		X	EA	CT	F	D			
3.4.2.9	Maintenance.		X	EA	CT		D			
3.4.2.10	Ground winds.		X	EA	CT		D			
3.4.2.11	Crashes.		X	EA	CT					
3.4.2.12	Ditching.		X	EA	CT					
3.4.2.13	Other ground loading conditions.		X	EA	CT	F	D			
3.4.3	Vibration and aeroacoustics.	XE	XE	ACE	AC	CT	FT			
3.5	Aeroacoustic durability.	XE	XE	ACE	AC	CT	FT			
3.5.1	Structure.	XEA	X	AC	AC	CT	FT			
3.5.2	Internal noise.	XE	XE	EA	AC	CT	F			
3.6	Vibration.	XA	X	AC	AC	CT	F			
3.7	Aeroelasticity.	X	XA	A	AR	ACT	ATF			
3.7.1	Aeroelastic stability.	X	X	A	AR	ACT	ATF			
3.7.1.1	Control surfaces and tabs.	X	XA	A	AR	ACT	TF			Q
3.7.1.2	Divergence.	X	XA	A	AR	ACT	AF			
3.7.1.3	Buzz.	X	XA	A	AR	CT	F			
3.7.1.4	External store carriage.	X	XA	A	AR	CT	ATF			
3.7.1.5	Panel flutter.	X	XA	A	AR	C	F			
3.7.1.6	Transonic aeroelastic phenomena.	X	X	A	AR	ACT	F			
3.7.1.7	Whirl flutter.	X	X	A	AR	ACT	AF			
3.7.1.8	Other controls and surfaces.	X	X	A	A	ACT	TF			
3.7.2	Aeroservoelasticity.	X	X	A	A	ACT	ATF			
3.7.3	Fail-safe stability.	X	XA	A	AR	ACT	F			
3.7.4	Free play of control surfaces and tabs.	X	XA	A	AR	ACT	F			Q
3.7.5	Environmental effects—aeroelasticity.	X	X	A	A	C	FD			
3.8	Required structure survivability—nuclear.	X	E	A	C		T			
3.9	Required structure survivability—non-nuclear.	X	E	A	C		DT			
3.10	Strength.			A	A	D	T	F		
3.10.1	Material properties.	E	QEX	X						

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		MILESTONES								
SPEC. PARA.	**REQUIREMENT**	**CA**	**SRR**	**PDR**	**CDR**	**FF**	**FCA SVR**	**GO**	**PCA**	**PROD**
3.10.2	Material processes.	E	QEX	X						
3.10.3	Internal loads.			A	A	D	T	F		
3.10.4	Stresses and strains.			A	A	D	T	F		
3.10.4.1	Fitting factor.				A					
3.10.4.2	Bearing factor.				A					
3.10.4.3	Castings.			A	C	D	T	F		
3.10.4.4	High variability structure.			A	A					
3.10.5	Static strength.			A	A	D	T	F		
3.10.6	Dynamic strength.									
3.10.7	Initial and interim strength flight release.				A	DP	F			
3.10.8	Final strength flight release.						DP	F		
3.10.9	Modifications.			A	A	D	T	F		
3.10.10	Major repairs, rework, refurbishment, and remanufacture	X	E	A	A	CTP	FQ			
3.11	Durability.		A	A	AC			AT		
3.11.1	Fatigue cracking/ delamination damage.		A	A	AC			AT		
3.11.2	Corrosion prevention and control.	EX	QAD	RC	QC			TQ		
3.11.3	Thermal protection assurance.		AX	RDQ	C			TQ		
3.11.4	Wear and erosion.			EA	DAQ		FC	Q		
3.11.5	Special life requirement structure.			A	AC			T		
3.11.6	NDT/I.	EX	QE	DER	EC	Q		Q		Q
3.12	Damage tolerance.			A	AT			AT		
3.12.1	Flaw sizes.		X	E	E					
3.12.2	Residual strength and damage growth limits.			A	AT			AT		
3.12.2.1	Slow crack growth structure.			A	AT			AT		
3.12.2.2	Fail-safe multiple load path structure.			A	AT			AT		
3.12.2.3	Fail-safe crack arrest structure.			A	AC			AT		
3.13	Durability and damage tolerance control.				E			Q		
3.14	Sensitivity analysis.			A	A			A		
3.15	Force management.			A	A	D				
3.15.1	Data acquisiton system provisions.				A	D				
3.16	Production facilities, capabilities, and processes		E	EP	EP	EP	EP	EP	EP	QP

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SPEC. PARA.	**REQUIREMENT**	**CA**	**SRR**	**PDR**	**CDR**	**FF**	**FCA SVR**	**GO**	**PCA**	**PROD**
3.17	Engineering data requirements	X	P	P	P	P	P	P	P	P

Verification Methods	
Code	Description
E	Examination
X	Contractor/Agency Agreement
A	Analysis
D	Demonstration
R	Development Test
C	Component Test
T	System Level Ground Test
F	Flight Test
Q	Process/Quality Control
P	Documentation

Milestones	
Code	Description
CA	Engineering Development Contract Award
SRR	System Requirement Review
PDR	Preliminary Design Review
CDR	Critical Design Review
FF	First Flight
FCA/SVR	Functional Configuration Audit and System Verification Review
GO	Production Go-Ahead
PCA	Physical Configuration Audit
PROD	Delivery of First Production Aircraft

Custodian:

Army -

Navy - AS

Air Force - 11

Preparing Activity:

Navy - AS

Agent:

Air Force - 11

Project No. 15GP-0002

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3. DOCUMENT TITLE
AIRCRAFT STRUCTURES

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

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