National Aeronautics and
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CONSTELLATION PROGRAM
STRUCTURAL DESIGN AND VERIFICATION REQUIREMENTS

ADL: The applicable and reference documents listed in this document may not have been developed from the approved Program ADL listing. Please review the approved ADL before use. (Reference: CxP 70013, Constellation Program Systems Engineering Management Plan, dated 8/31/06.)

Glossary: The terms within this Glossary may not have been developed from the approved Program Glossary. Please review the approved Program Glossary prior to use. (Reference: CxP 70072-ANX01, Constellation Program Management Systems Plan, Annex 1: Common Glossary and Acronyms, December 4, 2006 version dropped for baseline.) These listings will be validated by Program Baseline Re-sync.

Acronyms: The terms within this Acronyms listing may not have been developed from the approved Program Acronym list. Please review the approved Acronym list prior to use. (Reference: CxP 70072-ANX01, December 4, 2006 version dropped for baseline.) These listings will be validated by Program Re-sync.

REVISION AND HISTORY PAGE

Status	Revision No.	Change No.	Description	Release Date
Baseline	-		Baseline (Reference CxCBD C000103/1-1, dated 12/14/06)	12/18/06
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NOTE: Updates to this document, as released by numbered changes (Change XXX), are identified by a black bar on the right margin.

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1.0 INTRODUCTION

Structural design requirements for flight hardware are related to the methods to be used for structural design verification. This requirements document includes both structural design and verification requirements to assure that both are considered in the specification of detailed requirements for a component of Constellation Program flight hardware. Where appropriate, this document specifies design methodology to prevent conflicting analytical approaches utilized by different design and procurement organizations and the related impact on Program cost and schedules.

1.1 PURPOSE

The purpose of this requirements document is to specify common structural requirements for consistent design, development, and verification of all Constellation Program flight hardware.

1.2 SCOPE

The requirements in this document shall apply to all Constellation flight hardware including all Program elements, Line Replaceable Units, Orbital Support Equipment, Flight Support Equipment, and payloads. It is important to note that these requirements are to be included in all subsystem structural integrity activities and especially in the procurement specifications of subcontracted mechanical, actuation, fluid and propulsion subsystems.

Implementation and full compliance with the structural design and verification requirements does not relieve the hardware from compliance with fracture control, special design and verification requirements for glass and ceramic components such as windows, quality assurance requirements, or materials requirements that are applicable independent of structural requirements and invoked in CxP 70000, the CARD.

This is a design requirements document. Post-delivery anomalies and non-conformances will require case-specific analysis and/or test that are beyond the scope of this document.

1.3 CHANGE AUTHORITY/RESPONSIBILITY

Proposed changes to this document shall be submitted by a Constellation Program Change Request (CR) to the appropriate Constellation Program Control Board (CxCB) for consideration and disposition.

All such requests will adhere to the Constellation Program Configuration Management Change Process.

The appropriate NASA Office of Primary Responsibility (OPR) identified for this document is the Constellation Program Systems Engineering and Integration (SE&I) Office.

1.4 INTENDED USE

This document is intended for use by the Constellation Program and shall be a requirement for each Program participant.

1.5 APPROVAL BY NASA

Structural design and verification approvals required by this document shall be provided by the Constellation Program's designated technical authority.

1.6 PRECEDENCE

The CxP 70000, Constellation Architecture Requirements Document (CARD), defines the performance requirements for all Constellation Program Hardware. In the event of any conflict between the CARD and this document, the CARD takes precedence. In the event of any conflict between the text of this specification and an applicable document cited herein, the text of this specification takes precedence. In the event of any conflict between the text of this specification and a system Interface Requirements Document (IRD), the text of this specification takes precedence.

2.0 DOCUMENTS

2.1 APPLICABLE DOCUMENTS

The following documents include specifications, models, standards, guidelines, handbooks, and other special publications. The documents listed in this paragraph are applicable to the extent specified herein.

Inclusion of applicable documents herein does not in any way supersede the order of precedence specified in paragraph 1.6.

APPLICABLE DOCUMENT NO.	TITLE	Referenced in paragraph(s)…
CxP 70000	Constellation Architecture Requirements Document	1.2, 1.6, Table 3.10-1
CxP 70137	Constellation Program Structural Loads Control Plan	3.5, 3.5.1, 3.5.2, 3.9.1
NASA-STD-5012	Strength and Life Assessment Requirements for Liquid Fueled Space Propulsion System Engines	Table 3.10-1, 3.15, 4.15
20M02540	Assessment of Flexible Lines for Flow Induced Vibration	3.17

APPLICABLE DOCUMENT NO.	TITLE	Referenced in paragraph(s)…
ANSI/AIAA-S-080	Standard for Space Systems - Metallic Pressure Vessels, Pressurized Structures, and Pressure Components	Table 3.10-1, 3.17.5.1, 3.17.6, 4.17.5.1, 4.17.6
ANSI/AIAA-S-081A	Standard for Space Systems - Composite Overwrapped Pressure Vessels (COPV)	Table 3.10-1, 3.17.5.2, 4.17.5.2
ANSI/AIAA-S-087	TBD	3.17.1
TOR-2003 (8583)-2896	Space Systems – Flight Pressurized Systems	3.17, 4.17
CxP 70023	Design Specification for Natural Environments	3.21.2, 4.13
CxP 70136	Constellation Program Loads Data Book	3.21.3, 3.21.4
NASA-STD-6008	NASA Fastener Integrity	3.23.1, 4.23.1
MSFC-STD-486	Standard Torque Limits For Threaded Fasteners	3.23.1.2
SAE AS 8879	Screw Threads, UNJ Profile, inch	3.23.1.7
NSTS 08307	Criteria for Preloaded Bolts	3.23.1.8, 4.23.1.8
NASA-STD-5009	Nondestructive Evaluation Requirements For Fracture Critical Metallic Components	4.13.1.2
ASTM E1417-95a	Practice for Liquid Penetrant Examination	4.14.3
MSFC-RQMT-3479	Fracture Control Requirements for Composite and Bonded Vehicle and Payload Structures	Table 3.10-1, 4.16.2.1, 4.16.2.3, 4.16.2.4, 4.16.3
NSTS 08123	Certification of Flex Hoses and Bellows for Flow Induced Vibration	4.17.14
MSFC-SPEC-626	Test Control Document for Assessment of Flexible Lines for Flow Induced Vibration	4.17.14

APPLICABLE DOCUMENT NO.	TITLE	Referenced in paragraph(s)…
CxP 70036	Constellation Program Environmental Qualification and Acceptance Testing Requirements (CEQATR)	4.24

2.2 REFERENCE DOCUMENTS

The following documents contain supplemental information to guide the user in the application of this document.

REFERENCED DOCUMENT NO	TITLE	Referenced in paragraph(s)…
NASA-STD-5001A	Structural Design and Test Factors of Safety for Spaceflight Hardware	Table 3.10-1
NASA-STD-5019	Fracture Control Requirements for Spaceflight Hardware	3.16.1, 4.13.1.1
MIL-HDBK-17	Composite Materials Handbook	3.16.2
CxP 70008	Constellation Program Master Integration and Verification Plan (MIVP)	4.0
NASA SP-8003	Flutter, Buzz, and Divergence	4.27.4.2, 4.28.1.1.1
FAA-FAR Part 25	Airworthiness Standards: Transport Category Airplanes	4.28.1.1.1, 4.28.1.2.1
AFSC DH 3-2 (DN 4C7)	USAF Space Vehicles, Design Handbook, Series 3-0	4.28.1.1.1
MIL-A-008870 (USAF)	Airplane Strength and Rigidity – Flutter, Divergence and Other Aeroelastic Instabilities	4.28.1.1.1, 4.28.1.2.1
NASA-TM-X-73305	Astronautic Structures Manual	6.1
JSC 19652	Instructions for the Preparation of Stress Analysis Reports	6.2.1
MSFC-HDBK-505B	Structural Strength Program Requirements	Table 3.10-1

REFERENCED DOCUMENT NO	TITLE	Referenced in paragraph(s)…
(OSHA 29 CFR 1919.79)	OSHA Regulations (Standards – 29CFR) Wire Rope 1919.70	Table 3.10-1
AIAA-S-110	Space Systems – Structures, Structural Components and Structural Assemblies	Table 3.10-1
NASA SP-8007	Buckling of Thin-walled Circular Cylinders.	4.6
NWC TP 6575	Parachute Recovery Systems Design Manual	3.25.1
NASA SP-8008	Prelaunch ground wind loads	4.28.3.1, 4.28.3.2
NASA SP-8001	Buffeting During Atmospheric Ascent	4.28.4.3

3.0 DESIGN REQUIREMENTS

3.1 DESIGN ORGANIZATION STRUCTURAL ASSESSMENT PROGRAM

The organization responsible for structural design shall establish and maintain an effective structural analysis, structural test, and structural assessment program to evaluate and verify the structural integrity of Constellation Program flight hardware structure for both transport to and from orbit, and for on-orbit and planetary operations.

3.1.1 Structural Assessment After Critical Design Review (CDR)

Because the hardware design and the design data will evolve as the data such as loads, mass properties, temperatures and other environments are verified, it is NASA’s intent to update the hardware certification database so that the flight hardware is certified to the latest definition of the design and the latest definition of operating environments. It is therefore probable that the design database will mature after CDR, and design changes will need to be considered in response to these developments.

The organization responsible for structural design shall establish a program to evaluate how post-CDR changes in the natural and induced environments may affect the hardware.

3.2 APPROVAL OF DETAILED DESIGN CRITERIA

a) Any detailed design criteria used by the responsible design organization shall be consistent with this requirements document.

b) Detailed criteria which are not consistent with the requirements of this document shall be approved by NASA per paragraph 1.5.

3.3 STRENGTH AND STIFFNESS

a) Constellation Program structures shall have strength and stiffness in all necessary configurations and stages to support ultimate load without failure.

b) Detrimental deformation shall not occur at limit loads imposed during transportation to and from orbit and on-orbit operations, lunar or planetary operations, or during proof or acceptance testing.

c) Yielding shall not occur at limit loads imposed during ground transportation, rollout or handling operations.

3.4 MARGIN(S) OF SAFETY

Constellation Program flight hardware structure shall have +0.00 or positive Margin(s) of Safety (MS) for all limit and ultimate design load conditions, including the effect of aging on the hardware, with the following exception for permissible yielding.

3.4.1 Criteria for Yielding

Yielding of structure shall be acceptable only if all of the following conditions are satisfied:

a) The structural integrity of the component shall be demonstrated by adequate analysis and/or test.

b) There shall be no detrimental deformations that adversely affect the component/system function.

c) The service life requirements are met.

d) Unless otherwise specified, hydraulic, electrical, and other systems are not required to operate at loads and related deformations in excess of limit load.

e) Requirement 3.3 (c) is met.

3.5 LIMIT LOADS

a) Constellation Program structure shall meet its performance requirements as defined in the appropriate system's CxP System Requirements Documents (SRDs) when exposed to all appropriate static, transient, and random loads, pressure, and thermal effects for all phases of hardware service life, considering, when applicable, combined loading effects.

b) Limit load and load spectra shall be derived in accordance with the Constellation Program Structural Loads Control Plan, CxP 70137.

c) Analyses shall be performed for all anticipated loading events to establish limit loads.

d) Any load uncertainty factors used for design and assessment shall be approved by the appropriate NASA Loads Control Panel.

e) The probability of any structural load exceeding the defined structural limit loads shall be less than or equal to $^{1}/_{741}$ during the Program life for time-consistent loads.

f) When time consistency is unknown, the probability of any load associated with an independent event exceeding the defined limit loads shall be less than or equal to $^{1}/_{741}$. Load combinations shall be made by computing a root-sum-square of the peak independent time-consistent loads that meet this criterion, or a Monte Carlo analysis producing a load combination that meets this probability criterion may be used. Alternate load combination criteria may be used with the approval of the NASA Loads Control Panel.

g) The Constellation Program may define failure scenarios for which the vehicle is expected to survive. For these scenarios, the probability of any load exceeding the defined limit loads shall be less than or equal to $^{1}/_{44}$.

h) The probability of any random load exceeding the defined random limit loads shall not be more than $^{1}/_{741}$.

3.5.1 Integrated Loads

The coordination, generation, and dissemination responsibility for integrated element interface loads is defined in the Constellation Program Structural Loads Control Plan, CxP 70137.

a) For integrated flight, Constellation Program systems shall be designed to maintain required functionality and positive margins when subjected to all static and dynamic loads and thermal environments.

b) The Constellation Program flight vehicle structures shall maintain positive margins of safety for all induced loads and deformations, including dynamic interactions between mated stages.

c) All integrated configurations shall be considered.

3.5.2 Design Loads

Detailed design loads shall be derived for all life cycles of hardware in accordance with CxP 70137, Constellation Program Structural Loads Control Plan.

3.5.3 Redistributed Loads

Structures that are deployed, extended, or otherwise un-stowed to a configuration where they cannot withstand subsequent induced loads, or whose load paths are controlled by electro-mechanical devices shall be designed to maintain the factors of safety of Section 3.10 using the redistributed loads after 1 or 2 credible system failures commensurate with the hazard levels. Operational procedures may be used to restore the load path or limit the applied loads after the first failure.

3.5.4 Loads due to Friction

a) Friction forces shall be included when they increase the magnitude of the applied load or stress or when they are detrimental to the function of the part.

b) Design and analysis of CxP structures shall not consider friction when it is relieving.

3.6 BUCKLING AND CRIPPLING

a) All structural components that are subject to compressive and/or in-plane shear stresses under any combination of ground loads, flight loads, or loads resulting from temperature changes shall consider buckling failure modes.

b) Buckling shall not cause structural members that are subject to instability to collapse when ultimate loads are applied

c) Buckling shall not cause deformation at limit loads that degrades the functioning of any system or produces unaccounted for changes in loading.

d) Diagonal tension designs shall not be precluded.

3.6.1 Design Loads for Collapse

a) Design loads for collapse shall be ultimate loads, except that any load component that tends to alleviate buckling shall not be increased by the ultimate FS.

b) Destabilizing external pressure or torsional limit loads shall be increased by the ultimate FS but stabilizing internal-pressure loads shall not be increased unless they reduce structural capability.

3.7 DYNAMIC INTERACTIONS

3.7.1 Dynamic Coupling

Individual and integrated Constellation Program flight vehicle structural design shall be compliant with the specified control system requirements for a stable vehicle.

3.7.2 Slosh

Propellant tanks shall be designed to prevent or suppress coupling between fluids and vehicle structure and between fluids and the flight control system.

3.7.3 Pogo

All Constellation Program flight vehicle structures shall not exhibit unstable dynamic coupling with the liquid propulsion system for all mission configurations.

3.8 THERMAL EFFECTS

a) Constellation Program structures shall meet the performance requirements as defined in the appropriate system's CxP SRDs when thermal effects are combined, when applicable, with induced static and dynamic loads.

b) Thermal stresses/loads shall be combined with mechanical and pressure stresses/loads when they are additive but shall not be combined when they are relieving.

3.9 MATH MODELS

Loads and deformations utilized in Constellation Program flight hardware verification shall be based on verified structural math models.

3.9.1 Flight Hardware Math Models for Loads

Structural math models used to develop design loads for Constellation Program flight hardware consistent with each phase of the Program shall be in accordance with the Constellation Program Structural Loads Control Plan, CxP 70137.

3.9.2 Flight Hardware Math Models for Stress

The math models used to generate stresses, strains and internal loads for structural analysis shall be verified by the methodology selected from the requirements in paragraph 4.9.2 of this document.

3.9.3 Temperature Input for the Stress Model

Temperatures for the stress model shall be taken from a verified thermal math model.

3.10 FACTORS OF SAFETY

3.10.1 Minimum Factors of Safety

All Constellation Program flight hardware structure shall be designed to the minimum factors of safety (FS) specified in Table 3.10-1, Minimum Factors of Safety for Structure, or as modified by the factors specified in sections 3.0 and 4.0 of this document. Yielding is permitted per the specifications of paragraphs 3.4.1 and 4.4.1. Maximum design pressure is referred to here and in the rest of this document as MDP. Maximum Expected Operating Pressure is referred to here and in the rest of the document as MEOP.

Users of this table should note that certain acceptance test requirements specified in section 5.0 of this document may exceed the minimum factor of safety on yield for the hardware being provided. Hardware providers should ensure that no detrimental deformation will occur during acceptance testing, as required above in section 3.3.

Table 3.10-1 Minimum Factors of Safety for Structure

		Yield	Ultimate
A. Minimum Factors of Safety for Metallic Flight Structures (NASA-STD-5001A)			
Prototype		1.00	1.40
Qualification Test Factor	1.40		
Protoflight		1.25	1.40
Proof Test Factor	1.20		
Factors for hardware post-separation, not going to orbit, prototype program		1.0	1.25
Qualification Test Factor	1.25		
B. Minimum Factors of Safety for Non-metallic Flight Structures (NASA-STD-5001A)			
Prototype			
Uniform areas		N/A	1.40
Discontinuity areas		N/A	2.00
Qualification Test Factor	1.40		
Acceptance/Proof Test Factor	1.05* or 1.2		
*If Acceptance by the Damage Tolerance Approach per MSFC-RQMT-3479 is used. See paragraph 4.16.2.3.			
Protoflight			
Uniform areas			1.50
Discontinuity areas			2.00
Acceptance/Proof Test Factor	1.20		
C. Minimum Factors of Safety for Structural Soft Goods (NASA-STD-5001A) [excluding parachute & parafoil systems and Constellation Space Suit Systems]			
Safety critical			4.0

Table 3.10-1 Minimum Factors of Safety for Structure

		Yield	Ultimate
Proof or Acceptance Test Factor	1.2		
Qualification Test Factor	4.0		
Not safety critical			2.0
Proof or Acceptance Test Factor	1.2		
Qualification Test Factor	2.0		
D. Minimum Factors of Safety for Parachute and Parafoil Systems			
1. Subsonic systems			1.6
2. Supersonic systems			1.7
3. Safety critical components			2.0
E. Minimum Factors of Safety for the Constellation EVA Space Suit Element (CSSE) and Vehicle Interfaces Element (VIE)			
Proof or Acceptance Test Factor	1.2		
Qualification Test Factors			
c) Nominal tasks/events	2.0		
d) Off-nominal, contingency, or emergency events	1.5		
F. Minimum Factors of Safety for Wire Ropes and Cables (OSHA 29 CFR 1919.79)			4.0
Proof or Acceptance Test Factor	2.0		
G. Minimum Factors of Safety for Glass and Ceramic Structures, including windows			
Design factors for windows, glass and ceramic structure are defined in the CARD, CxP 70000.			
H. Minimum Factors of Safety for Rotating Machinery (liquid fueled engines see line I.1)		1.1	1.4
I. Minimum Factors of Safety for Pressure			
1. Engine Structures and Engine Compartments in Liquid Fueled Space Propulsion Systems			
Design and verification criteria for liquid fueled space propulsion system engines are defined in NASA-STD-5012.			
2. Pressurized Hardware (MSFC-HDBK-505B, ANSI/AIAA-S-080 and ANSI/AIAA-S-081)			
a. Lines and fittings less than 1.5 inches (38 mm) dia. (OD)			
Proof Pressure [1]	= 1.50 X MDP		
Design Burst Pressure	= 4.00 X MDP		
b. Lines and fittings, 1.5 inches (38 mm) dia. or greater			
Proof Pressure [1]	= 1.50 X MDP		
Design Burst Pressure	= 2.50 X MDP		
c. Other pressure system components such as actuating cylinders, valves, regulators, filters, switches, heat pipes and line-installed alignment bellows			
Proof Pressure [1]	= 1.50 X MDP		
Design Burst Pressure	= 2.50 X MDP		
d. Metallic Pressure Vessels and Sealed Containers			

Table 3.10-1 Minimum Factors of Safety for Structure

		Yield	Ultimate
Proof Pressure [1]	= 1.50 X MDP		
Design Burst Pressure	= 2.00 X MDP		
e. Composite Overwrapped Pressure Vessels			
Proof Pressure [1]	= 1.25 X MDP		
Design Burst Pressure	= 2.00 X MDP		
f. Doors, Hatches and Habitable Modules		1.65	2.00
Internal pressure only			
Proof Pressure [1]	= 1.50 X MDP		
Negative pressure differential		N/A	1.50
g. Flex hoses, all diameters			
Proof Pressure [1, 4]	= 2.00 X MDP		
Design Burst Pressure	= 4.00 X MDP		
h. Pressurized Structures except for (i and j)		1.1	1.4
Proof Pressure [1]	= 1.10 X MDP		
Ultimate Pressure	= 1.40 X MDP		
i. Metallic Propellant Tanks and Solid Rocket Motor Cases that are Pressurized Structures		1.1	1.4
Proof Pressure [1]	= 1.05 X MDP[6]		
j. Composite Propellant Tanks and Solid Rocket Motor Cases that are Pressurized Structures		N/A	1.5
Proof Pressure [1]	= 1.20 X MDP[6]		
3. Combined pressure, thermal and mechanical loading[1, 2, 3, 4, 5] (AIAA-S-110)			
$K_1 L_{mechanical} + K_2 L_{thermal} + K_3 L_{pressure}$ = Total (Limit or Ultimate) Load			
J. Joint Separation			
Non-critical Joint		N/A	1.20
Critical Joint		N/A	1.40
Prototype test for critical joint			
Qualification Test Factor	1.40		
Protoflight test for critical joint			
Acceptance/Proof Test Factor	1.20		

Table 3.10-1 Minimum Factors of Safety for Structure	Yield	Ultimate

Notes:

General note – the parenthetical document references next to some of the table entries are given for traceability; these notations are not requirement call-outs from the referenced documents.

1. Proof factor determined from fracture mechanics service life analysis shall be used if greater than minimum factor.
2. See paragraph 6.1.1 when pressure loads have a relieving or stabilizing effect on structural capability.
3. See paragraph 3.8 when thermal conditions are relieving.
4. In a system with fluid lines and flex hoses, the individual flex hoses shall be proof tested to 2.00 X MDP; this factor does not apply at the assembly level.
5. K_i = design factor of safety on yield or ultimate from this table, as applicable, when term is additive to the algebraic sum, ΣL

   $K_{1i} = 1.0$, $K_2 = 0.0$, $K_3 = 1.0$ when term is subtractive to the algebraic sum, ΣL

   $L_{mechanical}$ = internal loads (forces, stresses, and/or strains) due to externally applied mechanical limit loads; e.g., inertial loads, aerodynamic pressure

   $L_{thermal}$ = internal loads (forces, stresses, and/or strains) due to thermally-induced loads at the maximum and minimum predicted temperatures including modeling uncertainty margins

   $L_{pressure}$ = internal loads (forces, stresses, and/or strains) due to design limit pressures
6. See section 3.17.3.1 for an exception allowing the use of MEOP.

3.10.1.1 Factor of Safety for Negative Pressure Differential

A negative, or crushing, pressure differential on habitable modules shall use an ultimate factor of safety of 2.0 if certification for these loads is by analysis only.

3.10.1.2 Post-landing Factor of Safety of Pressure Vessels

Minimum design factors of safety for pressure vessels shall be maintained under conditions encountered at any continental United States or contingency landing site without post-landing services.

3.10.2 Emergency Events

Program-defined emergency design loads shall be applied with an ultimate factor of safety of 1.0.

3.10.3 Analysis-only Factors of Safety

In this document, there are no published “analysis-only” factors of safety that automatically allow structural verification without testing. A higher factor of safety alone is insufficient to account for structural uncertainties or modeling errors that a test program will uncover.

For metallic structures only, it may be permissible to verify structural integrity by analysis alone without strength testing, provided an acceptable engineering rationale is developed. Increasing the design factors of safety does not by itself justify this “no-test” approach. Some examples of criteria on which to base such an approach are as follows:

a) The structural design is simple (e.g., statically determinate) with easily determined load paths; it has been thoroughly analyzed for all critical load conditions; and there is a high confidence in the magnitude of all significant loading events.

b) The structure is similar in overall configuration, design detail, and critical load conditions to a previous structure which was successfully test verified, with good correlation of test results to analytical predictions.

c) Development and/or component tests have been successfully completed on critical, difficult to analyze elements of the structure. Good analytical model correlation to test results has been demonstrated.

If a “no test” option is proposed, the approach and the factors of safety to be used in the structural analysis and life verification shall be included in the structural verification plan and approved in writing by NASA per paragraph 1.5.

3.11 STRUCTURAL MATERIALS CRITERIA

Specifications for materials used in the fabrication, processing, and testing of flight hardware and components can be found in other program documents as described in paragraph 1.2.

3.11.1 Material Design and Analysis Thickness

The drawing minimum thickness shall be used in stress calculations of pressure vessels, stability critical structure, and single load path structure. Actual as-built dimensions may be used in stress calculations when available.

3.11.2 Structural Material Allowable Properties

a) Material “A” or equivalent allowable values shall be used in all applications where failure of a single load path could result in a loss of structural integrity in primary structure.

b) Material “B” or equivalent allowable values shall not be used except in redundant structure in which the failure of a component would result in a safe redistribution of applied loads to other load-carrying structure.

c) Material “S” allowables may be used in lieu of “A” or “B” allowables where batch lot acceptance testing is a procurement requirement.

d) Design allowables specific to the material used in a structure may be developed if lot specific testing of that material is performed to determine the mechanical properties of the actual material used in that particular item. Use of these "premium" properties will require NASA approval, via a Materials Usage Agreement (MUA) as described in other program requirements as discussed in paragraph 1.2.

3.11.3 Avoiding Creep

a) Materials shall be selected to preclude accumulated damage from creep in the Constellation Program flight hardware environment.

b) If selection of a structural material which exhibits creep phenomena in the Constellation Program flight hardware environment is unavoidable, then NASA approval per paragraph 1.5 shall be obtained prior to use.

3.11.4 Castings

Requirements for castings (such as material property and fracture control requirements, among others) are contained in other Program-imposed requirement and verification documents as discussed in paragraph 1.2.

3.12 DESIGN FACTORS

3.12.1 Joint Fitting Factor

In the structural analysis of fittings, a fitting factor of 1.15 shall be used on limit and ultimate loads for joints which contain fittings whose strength is not proven by limit and ultimate load tests in which the actual stress conditions are simulated and measured in the fitting and surrounding structure.

A fitting factor need not be used with limit and ultimate loads where the type of joint, such as a continuous row of fasteners in sheet or plate, a welded or bonded joint, or a scarf joint in metal or plastic, etc., is strength-verified based on comprehensive limit and ultimate tests.

3.12.1.1 Joint Fitting Factor Application

This factor shall apply to all portions of the fitting, the means of fastening, and the bearing on the members joined.

3.12.1.2 Joint Fitting Factor for Integral Fittings

In the case of integral fittings, the part shall be treated as a fitting up to the point where the section properties become typical of the member away from the joint.

3.12.2 Bearing Factor for Joints Subjected to Hammering Action

A bearing factor of 2.0 shall be used in conjunction with the yield and ultimate FS for the design of a joint subjected to shock or hammering action.

3.13 STRUCTURAL LIFE REQUIREMENTS

All structural components shall have adequate structural life according to the specific requirements identified in the appropriate system's CxP SRD.

3.13.1 Cumulative Damage During Service Life

All flight hardware structure shall be designed to preclude failure resulting from cumulative damage due to cyclic or repeated loading and sustained stress during the design service life, using a scatter factor of 4 for fatigue testing or analysis as described in section 4.13.1.1 or scatter factor of 2 or 4 for certain kinds of durability analysis as described in section 4.13.1.2.

3.13.2 Creep

All flight hardware structure shall be designed to preclude cumulative strain as a function of time, i.e., creep, which could result in rupture, detrimental deformation, or collapse, (e.g., buckling) of compression members during the design service life, using a scatter factor of 4 for analysis as described in paragraph 4.13.2.

3.14 BERYLLIUM STRUCTURES

Beryllium used in the Constellation Program for structural components shall meet the requirements in section 4.14.

3.15 LIQUID FUELED SPACE PROPULSION SYSTEM ENGINE STRUCTURES

Design of structural components of liquid fueled space propulsion systems shall comply with NASA-STD-5012, Strength and Life Assessment Requirements for Liquid Fueled Space Propulsion System Engines. Factors of safety and other design and verification criteria for these hardware items may be found in NASA-STD-5012.

3.16 COMPOSITES/BONDED STRUCTURE DESIGN

3.16.1 General Design Requirements

All composite/bonded structures will, as a minimum, meet prescribed structural design requirements specified in this document and the fracture control requirements specified in NASA-STD-5019, paragraph 4.1.1.7.

Minimum factors of safety for composites/bonded structures are listed in Table 3.10-1.

3.16.2 Composites/Bonded Structure Design and Analysis Practices

The designer/manufacturer shall use only manufacturing processes and controls (coupon tests, sampling techniques, etc.), design standards and analysis practices that are demonstrated to be reliable and consistent with established aerospace industry practices for composite/bonded structures. MIL-HDBK-17 may be used as a reference.

3.16.3 Composite Structure Inadvertent Damage Protection

A comprehensive plan for the prevention of inadvertent damage to manufactured composite structural components that may result from handling, transportation, storage or final assembly shall be prepared by the hardware developer and approved by the Constellation Program designated technical authority.

3.16.4 Composites/Bonded Structure Life Requirements

Composite/bonded structures shall be designed for a minimum of four service lifetimes when considering maximum damage/flaws due to manufacture and handling which could not be detected by the inspection process specified.

3.16.5 Bonded Joints

All bonded joints shall, as a minimum, meet prescribed structural design requirements specified in this document.

3.17 DESIGN REQUIREMENTS FOR PRESSURE SYSTEMS

Pressurized hardware is any hardware item that is exposed to and largely structurally designed to carry acting pressure, such as pressure vessels, other pressurized components such as lines, fittings, valves, and bellows, and pressurized structures and habitable modules. Refer to the glossary of this document to differentiate between pressure vessels, habitable modules, and pressurized structure.

3.17.1 General Requirements for Pressurized Systems

a) Pressurized systems shall be designed and fabricated as specified in the latest revision of Aerospace Report No. TOR-2003 (8583)-2896, *Space Systems -- Flight Pressurized Systems,* as tailored herein.

   Note: This TOR is a draft version of a proposed standard ANSI/AIAA S-087.

b) The Constellation Program loads and environments specified in paragraph 3.5 shall be used for design in place of loads and environments specified in standards.

3.17.2 Factor of Safety Requirements for Pressurized Hardware

Minimum factors of safety for pressurized hardware are in Table 3.10-1. The minimum factors of safety provided in Table 3.10-1 shall prevail unless specifically stated otherwise in this document.

3.17.3 Use of Maximum Design Pressure (MDP)

All pressurized hardware shall be designed, tested, and analyzed employing the Maximum Design Pressure (MDP) instead of the Maximum Expected Operating Pressure (MEOP) referenced in other standards.

3.17.3.1 Exception Allowing Use of MEOP

In cases where MDP is not defined because two-fault tolerant pressure control is not provided, an MEOP condition may be substituted with approval of the appropriate element technical authority.

This approval shall be obtained from NASA per paragraph 1.5 and shall be limited to cases where a two-fault tolerant pressure regulation device logic is unobtainable or impractical, such as solid rocket motors, combustion chambers, and pyrotechnic devices.

3.17.4 Fracture Control for Pressurized Hardware

Pressurized hardware design and fabrication requirements related to fracture control are contained in other program-imposed requirement and verification documents as discussed in paragraph 1.2.

3.17.5 Pressure Vessel, Pressurized Structure, and Sealed Container Design Requirements

Pressure vessels, pressurized structure, and sealed containers shall maintain dimensional stability required for functionality of structural and mechanical attachments, pressure connections, and openings for doors or hatches throughout their service life in the applicable environments.

3.17.5.1 General Requirements for Metallic Pressure Vessels, Sealed Containers, and Pressurized Structures

Metallic pressure vessels, sealed containers, and pressurized structures shall be designed and fabricated as specified in the most recent revision of ANSI/AIAA-S-080, Standard for Space Systems - Metallic Pressure Vessels, Pressurized Structures, and Pressure Components, as tailored herein.

3.17.5.2 General Requirements for Composite Overwrapped Pressure Vessels

Composite Overwrapped Pressure Vessels (COPVs) shall be designed and fabricated as specified in the latest revision of ANSI/AIAA-S-081, Standard for Space Systems - Composite Overwrapped Pressure Vessels (COPV), as tailored herein.

3.17.6 Requirements for Pressurized Lines, Fittings, and Other Pressurized System Components

Pressurized lines, fittings, and other pressurized system components shall be designed and fabricated as specified in the latest revision of ANSI/AIAA-S-080, as tailored herein.

3.17.6.1 Restraints for Pressurized Lines or Flexible Hoses

a) Pressurized lines or flexible hoses shall be restrained or otherwise captured.

b) Restraints for pressurized lines or flexible hoses shall prohibit whipping of the hose end if it is suddenly opened due to a failure or unexpected event.

c) A dynamic factor of 1.1 shall be used to calculate the maximum impact force on the restraint due to the open line moving through the distance of the flexure of the restraint under maximum hose pressure. Note that the total factor on the restraint will be at least 1.4 (from Table 3.10-1) multiplied by 1.1.

3.17.6.2 Safe Disconnect for Pressurized Connections

Pressurized connectors shall safely vent before separation.

3.17.7 Habitable Modules

Habitable modules are treated separately from pressure vessels and pressurized structures.

3.17.7.1 Doors and Hatches in Habitable Modules

Habitable modules shall be designed to withstand pressure and applicable loads with the doors and/or hatches in both the closed and open conditions for both ground and space environments.

3.17.7.2 Dimensional Stability for Habitable Modules

Habitable modules shall maintain dimensional stability required for functionality of structural and mechanical attachments, pressure connections, and openings for doors or hatches throughout their service life in applicable environments.

3.17.8 Negative Pressure Design Requirements

Pressure system components which are subject to negative pressures shall not collapse at 2.5 times the maximum negative pressure differential consistent with the definition of MDP. These components include pressure vessels, sealed containers, and flex hoses but not habitable modules, doors, and hatches.

The negative pressure requirements for habitable modules, doors, and hatches are shown in Table 3.10-1.

3.17.8.1 Negative Pressure Damage Prevention for Pressure Vessels

a) Pressure vessels shall be evaluated for susceptibility to damage by negative pressures that may occur during fabrication, testing, installation, transportation, storage, servicing, nominal and contingency operations, and maintenance.

b) Those vessels identified as susceptible to damage shall be appropriately tagged and protected against negative pressure during the life cycle of the tank, particularly during manufacturing and testing, by detailed formal procedures or protective devices.

3.17.9 Pressure Control

Where pressure regulators, relief devices, and/or a thermal control system (e.g., heaters) are used to control pressure, they shall collectively be two-fault tolerant from causing the pressure to exceed the MDP of the system.

3.17.10 Pressure Stabilized Structures

a) Structures which are pressure stabilized and must contain a minimum pressure to maintain the required ultimate factors of safety to insure structural integrity under all load combinations shall meet all the requirements for pressurized structure in Table 3.10-1, paragraph 3.17.2, and section 5.0.

b) The existence of the minimum required pressure shall be verified prior to the application of safety critical loads into the system.

3.17.11 Burst Discs

When burst discs are used as the second and final control of pressure to meet the requirements of paragraph 3.17.9, they shall be designed to the following requirements:

a) Burst discs shall incorporate a reversing membrane against a cutting edge to ensure rupture.

b) Burst disc design shall not employ sliding parts or surfaces subject to friction and/or galling.

c) Burst discs shall be sized to allow mass flow rate to keep the pressure system below its MDP.

d) Burst disc materials shall be compatible with the fluid in contact to prevent build-up or deterioration of surface properties which would defeat the burst disc function.

e) Fluid or gases released after burst disc rupture shall not pose a catastrophic or critical hazard.

3.17.12 Dewars

Fracture control requirements for dewars are given in other documents as described by paragraph 1.2. Dewar/cryostat systems shall be designed in accordance with the following:

a) Dewars shall meet the requirements for pressure vessels specified herein.

   1. Dewars shall be designed to MDP or the pressure achieved under maximum venting conditions whichever is higher

   2. Dewar/cryostat systems shall maintain structural integrity under all external loads.

b) Outer shells (i.e., vacuum jackets) shall have pressure relief capability to preclude rupture in the event of pressure container leakage.

c) The relief devices shall be capable of venting at a rate to release full flow without outer shell rupture.

d) Relief devices shall be redundant and individually capable of full flow.

e) Pressure relief devices which limit maximum design pressure shall be certified to operate at the required conditions of use.

f) Non-hazardous fluids may be vented into the inter-element volume if analysis shows that a worst case credible volume release will not affect the structural integrity or thermal capability of the integrated vehicle or will not become a catastrophic hazard.

3.17.13 Secondary Volumes

Secondary compartments or volumes that are integral or attached by design to pressure system components and which can become pressurized as a result of a credible single barrier failure in the pressure system component shall be designed for pressure with a minimum safety factor of 1.5 based on MDP of the pressure system.

3.17.13.1 Allowable Venting for a Secondary Pressurized Volume

If external leakage would not present a catastrophic hazard, the secondary volume may be vented or equipped with a relief provision in lieu of designing for system pressure.

3.17.13.2 Credible Failures in a Secondary Pressurized Volume

a) Redundant seals in series which have been acceptance pressure tested individually prior to flight shall not be considered credible single barrier failures.

b) Failures of structural parts, such as pressure lines and tanks, and properly designed and tested welded or brazed joints shall not be considered single barrier failures.

c) Some items like metal bellows or diaphragms designed to a safety factor of 2.5 on the MDP may be excluded from the category of credible single barrier failures. These items shall be certified for all operating environments including fatigue conditions.

3.17.14 Flow-Induced Vibration

All flexible hoses and bellows shall be designed to exclude or control flow-induced vibrations in accordance with MSFC-DWG-20M02540, Assessment of Flexible Lines for Flow Induced Vibrations.

3.18 STRUCTURAL DESIGN REQUIREMENTS FOR ROTATING MACHINERY

The requirements in this section are intended to address design issues for equipment where rotational effects are structurally significant, such as motors, gyroscopes, flywheels, transmissions, high-speed gears, and pumps that aren’t part of the liquid propulsion engine system (for the liquid propulsion engine system see paragraph 3.15). These requirements shall apply to any rotating machinery where a failure would cause a catastrophic or critical hazard.

Fracture control requirements for rotating machinery are contained in other Program-imposed requirement and verification documents as discussed in paragraph 1.2.

3.18.1 Design Loads for Rotating Machinery

The rotating machinery design loads shall comprise the loads defined in section 3.5 and self-induced loads.

3.18.1.1 Rotor Dynamics

a) Critical speeds shall not be of a type or of a frequency response that would be deleterious to the safety and operation of the rotating machinery system.

b) The required frequency margins for any rotating machinery system shall be specified by the system’s procuring authority.

3.18.1.2 Stability Requirements for Rotating Machinery

Using isolation, damping and/or related means to permit stable performance, rotating parts shall be free of instability.

3.18.2 Strength Requirements for Rotating Machinery

Minimum factors of safety for all rotating machinery components are given in Table 3.10-1 (H). Stresses shall be calculated at maximum design speed and then factors of safety applied.

3.18.3 Fatigue Life Requirements for Rotating Machinery

Rotating machines and their components shall have adequate structural life with a low-cycle fatigue life of 4.0 times the service life, and a high-cycle fatigue life of 10.0 times the service life.

3.19 DESIGN REQUIREMENTS FOR STRUCTURAL SOFT GOODS

Straps, fabrics, inflatable structures, gossamer structures and other soft goods that carry structural loads upon launch or deployment shall be considered structural soft goods. Structural soft goods whose failure would pose either a critical or catastrophic hazard are safety critical.

Minimum factors of safety for all structural soft goods except parachutes and parafoils are given in Table 3.10-1 (C).

For parachute or parafoil system design requirements, see section 3.25.1, Special Considerations for Parachute Systems.

3.20 CONSTELLATION EVA SPACE SUIT ELEMENT (CSSE) AND VEHICLE INTERFACES ELEMENT (VIE)

Subsystems of the CSSE or VIE that retain pressure or carry loads shall be considered structural and will comply with the appropriate requirements contained within this document. Minimum factors of safety for the CSSE and VIE are given in Table 3.10-1.

3.21 STRUCTURAL INTEGRITY IN THE SPACE ENVIRONMENT

3.21.1 Structural Degradation from Material Erosion - General

Potential structural erosion, e.g., Plasma Environmental Effects Compatibility-induced, atomic oxygen, and other natural environments, during the design life shall be included in the design and analysis of the structure.

3.21.2 External Structural Integrity after MM/OD Impact

Constellation Program micro-meteoroid and orbital debris critical flight structure (see Figure 3.21-1) shall be designed to meet the performance requirements as defined in the appropriate system's CxP SRDs when exposed to impacts by meteoroids and space debris as defined in CxP 70023, the Constellation Program Design Specification for Natural Environments.

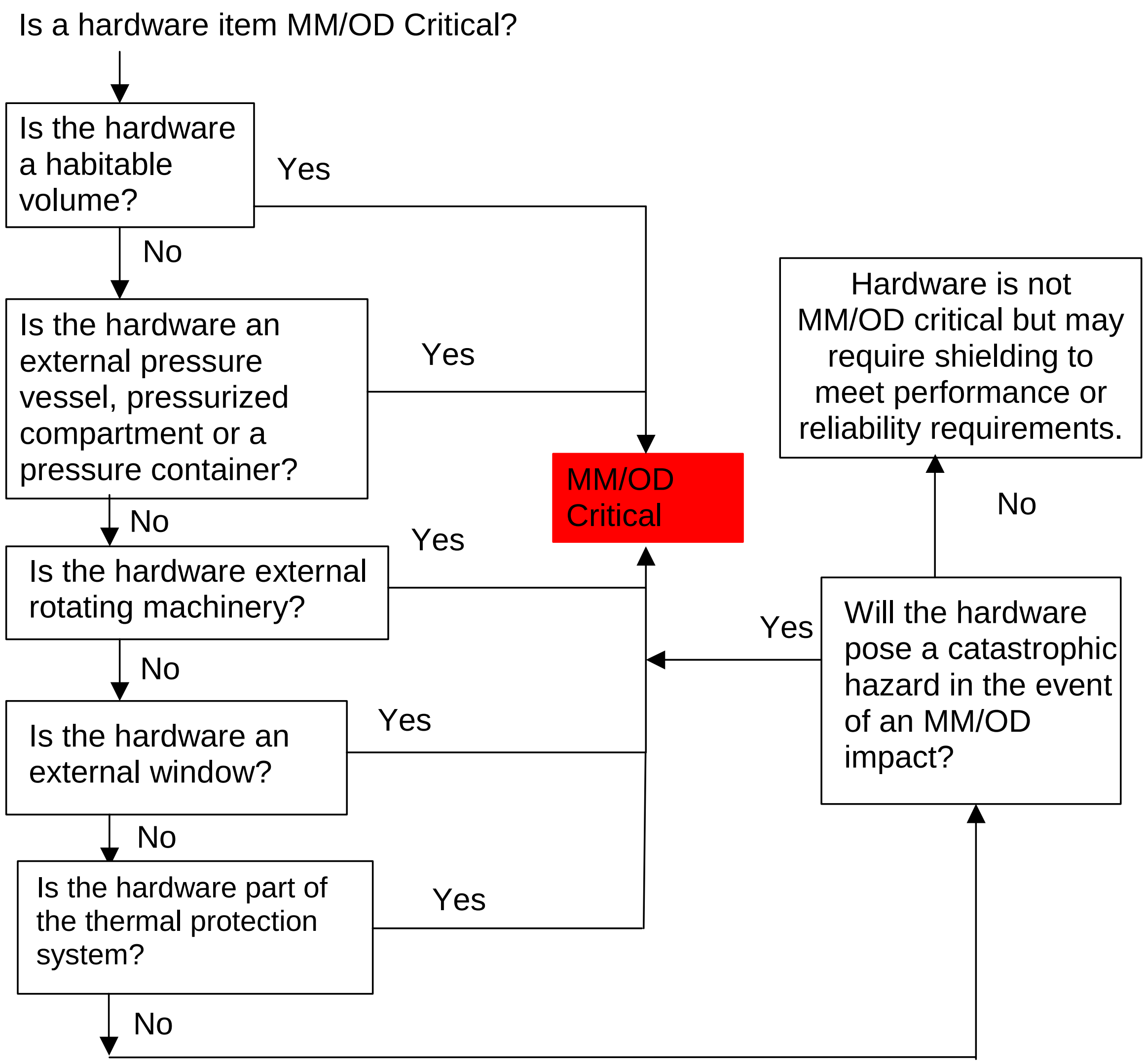

Figure 3.21-1 MM/OD Criticality Decision Flow Chart

3.21.3 External Structural Integrity After EVA Crew Induced Loads

Constellation Program external structure shall meet its performance requirements as defined in the appropriate system's CxP SRDs when exposed to EVA crew induced loading as defined in CxP 70136, Constellation Program Loads Data Book.

3.21.4 Internal Structural Integrity after IVA Crew Induced Loads

Constellation Program internal structure shall meet its performance requirements as defined in the appropriate system's CxP SRDs when exposed to IVA crew induced loading as defined in CxP 70136, Constellation Program Loads Data Book.

3.22 SECONDARY STRUCTURE ACCOMMODATION FOR HUMAN INTERFACE

3.22.1 Inspection, Maintenance and Repair

Interior secondary structures, stand-offs, attachment hardware, utility runs, partitions, walls, and close-out structure shall be designed for accessibility to other hardware for inspection, maintenance, and repair.

3.22.2 Interior Close-out

Close-out structure shall be used to prevent items from becoming lost in a low-gravity environment.

3.22.3 Ground and In-space Operational Access Doors

Secondary structures such as compartment doors and access panels accessible by the crew shall be operational in both ground and in-space environments.

3.22.4 Fasteners for Close-out Panels and Access Doors

For close-out panels and access doors that will be used multiple times during ground processing and mission operations, high cycle fasteners shall be specified.

3.23 FASTENERS AND JOINTS

3.23.1 Fastened Joints

Fasteners shall meet the specifications in NASA-STD-6008.

3.23.1.1 Structural Fastener Retention

a) Non-verifiable retention methods such as liquid locking compounds (LLCs) shall not be used.

b) Fastener systems used in non-permanent installation applications where the internal thread is not readily accessible or replaceable, that utilize prevailing torque self-locking features, shall have the locking feature located on the externally threaded fastener.

3.23.1.1.1 Fastener Retention Redundancy

Each ground-installed fastener, in joints not subject to rotation, whose failure would cause a redistribution of structural loads shall incorporate two separate verifiable locking features.

Preload may be used as one of the locking features combined with a conventional aerospace secondary locking feature, so long as the preload level is adequate to produce the intended locking effect.

3.23.1.1.2 Structural Fasteners in Joints Subject to Rotation

Structural fasteners used in joints that are subject to rotation in operation shall either

- Utilize at least one non-friction locking device, or
- Utilize a self-locking nut with a shoulder bolt or a standard bolt in a sleeve, wherein the grip length or the length of the sleeve shall ensure that sufficient end play is provided to preclude binding when the self-locking nut is tightened.

3.23.1.1.3 Use of Snap Rings and Cotter Pins

a) Where snap rings or cotter pins are used, new snap rings or cotter pins shall be used once the previous snap ring or cotter pin is removed.

b) Yielding of snap rings during installation shall be prohibited.

3.23.1.2 Structural Fastener Torque Specification

a) Preload torques and running torques (also known as prevailing torques), along with their acceptable ranges, shall be specified on the drawings controlling their installation.

b) The required torque for fasteners with locking features shall be clearly specified on the drawing as “above running torque.” In cases where the running torque is very small compared to the installation torque (usually occurring with larger diameter fasteners) the torque on the drawing does not have to be specified as “above the running torque” with approval by the responsible hardware engineer.

c) Torque-tension testing per MSFC-STD-486 or specifications with torque values based on torque-tension testing shall be used to establish torque and re-torque limits for threaded fasteners and for use of torque wrenches on such fasteners.

d) When fasteners requiring a running torque are used on bolted joints assembled or disassembled by the flight crew, both the running torques and preload torque shall be considered when developing the in-flight procedures for torquing.

3.23.1.2.1 Torque Application

a) Torque shall be applied from the nut of the fastening system to the maximum extent practical when a nut is accessible. Where clearance is a problem, torque may be applied from the bolt head of the fastening system, but the torque specification shall take into account the effect of tightening from the bolt head side to achieve the proper preload.

b) When multiple fasteners are used for a joint assembly, an appropriate torque pattern with a prescribed incremental increase interval shall be specified to ensure the proper preload is induced in the joint.

3.23.1.2.2 Running Torque

a) Running (self-locking or prevailing) torque and breakaway torque values exhibited during installation through the locking feature shall meet the requirements of the self-locking fastener procurement specification for each installation.

b) Fasteners that do not meet the running torque specification shall be replaced.

3.23.1.2.3 Wrenching Torque Requirements

Design torque values shall not exceed the specification wrenching torque values for fasteners and nuts.

3.23.1.3 Inserts

a) Threaded inserts shall be used in applications that require tapped holes in aluminum, magnesium, plastic, or other materials that are susceptible to galling or thread damage.

b) Fasteners shall engage a minimum of 1x fastener diameter (D) full threads into the threaded insert with a goal of 1.5xD, and shall ensure the development of the required joint tensile strength.

c) When a locking feature is utilized, the fastener shall engage a minimum of 2 full threads past the locking feature.

d) Thread engagement shall be sufficient to develop the required joint tensile strength without bottoming out the fastener or placing the threads in bearing.

3.23.1.4 Thread Engagement

a) If nuts or nutplates are used, a minimum of two complete, perfectly developed, screw threads shall protrude beyond the end of the nut or nutplate.

b) Fasteners thread engagements in a joint fitting shall ensure the development of the required joint tensile strength and engage a locking feature, if present.

c) Self-locking fasteners shall extend two complete screw threads past the locking feature.

d) Fastener thread engagement shall be designed to ensure that the joint is bolt critical rather than thread shear critical unless the joint is a shear design or the applied tension loads or tension loads due to fastener preload are low.

3.23.1.5 Grip Length Adjustment

3.23.1.5.1 Adjusting with Dash Numbers

a) Fasteners more than two dash numbers above or below the specified dash number shall not be used to adjust grip length.

b) Fasteners two dash numbers above or below the specified dash number may be used where no interference results and the minimum thread protrusion requirements are satisfied.

3.23.1.5.2 Adjusting with Washers

a) Washers shall not be used to provide fastener joint fit-up in lieu of grip length adjustment unless torque-tension testing with the adjusted number of washers has been performed.

b) The number of washers used in combination with a fastener shall be limited to four, two under the head (one countersunk) and two flat washers under the nut.

c) Countersunk washers shall be used under fastener heads with the countersink adjacent to the fastener head.

3.23.1.6 Structural Strength Issues in Fastener Specifications

a) Structural fasteners shall not be used where threads are placed in bearing.

b) The unthreaded portion of the shank shall not protrude through the parts being joined such that the nut bottoms out on the unthreaded shank.

c) Threads shall not be allowed in bending.

3.23.1.7 Fastener Thread Specification Requirements

a) Fatigue-sensitive structural fasteners and fasteners with ultimate tensile strength of 160 ksi or higher shall be of unified thread form UNJ, class 3 fit, designed and procured in accordance with SAE AS 8879.

b) Externally threaded fasteners utilizing the UNR or UNJ thread form shall have threads that are rolled after heat treatment.

3.23.1.8 Preloaded Joint Criteria

a) Preloaded joints shall be assessed in accordance with NSTS 08307, Criteria for Preloaded Bolts, unless all of the following criteria are met:

3. The joint is not a tension joint in which gapping cannot be tolerated. A “tension joint” is defined as a joint in which the largest component of the applied load is tension.
4. Fastener prying effects are correctly accounted for.
5. The fastener is in a local pattern of two or more fasteners.
6. The fastener is a high-quality military standard, national aircraft standard, or equivalent commercial fastener that is fabricated and inspected in accordance with aerospace flight quality hardware specifications.
7. The fastener preload is well controlled, using test-verified torque-tension relationships and nominally 65 percent of F_{ty}. Exceptions shall be documented with rationale, such as secondary structural application.
8. The joint fittings are metallic.
9. No significant thermal loading that changes preload is present during mechanical loading.
10. The joints are not for pressure containment, including crew module environmental containment, or hazardous material containment.

b) If the above criteria are met, bolted connection margins of safety may be assessed without fastener preload, yield, or gapping considerations.

3.23.1.9 Nonstandard Fasteners

NASA approval per paragraph 1.5 shall be obtained for the use of nonstandard or specially manufactured fasteners.

3.23.1.10 Clamping of Soft Goods

The analysis methodology for fastened joints involving the clamping of soft goods shall be provided for NASA approval per paragraph 1.5.

3.23.2 Design Requirements for Welded Joints

The structural design of welded joints and welded joint repairs shall be based on material properties developed from test data in accordance with other program requirements as described in paragraph 1.2.

3.23.2.1 Design Allowables for Welded Joints

Material properties test data shall provide design allowables for the weld process and weld repair process used and the specific joint configuration.

3.23.2.1.1 Acceptable Dimensional Variations for Welded Joints

The structural design of the welded joint and the design allowables shall account for the acceptable dimensional variations for the welded joint and joint repair. As-built dimensions of the welded joint or welded joint repair may be used to establish design allowables.

3.23.2.1.2 Non-destructive Evaluation of Welded Joints

The structural design of the welded joint and the design allowables shall account for the sensitivity of the Non-Destructive Evaluation (NDE) methods used for the welded joint and joint repair.

3.23.2.2 Engineering Drawing Requirements for Welded Joints

The acceptable dimensional variations and the sensitivity of the non-destructive method used for the welded joint and joint repair shall be specified on the engineering drawings.

3.24 CRITICAL SEAL REDUNDANCY

Critical seals shall be redundant per **Table 3.24-1**.

Table 3.24-1 Seal Redundancy and Verifiability Requirements

Seal	Redundancy and Verifiability Requirements [2,3,4,5]		
	$0.5 < D \leq 6.0$ inches	$D > 6.0$ inches	$D \leq 0.5$ inches
Feed-through connection [1]	A	B	C
Rotary	A	B	C
Windows	A	B	C
Hatches/Doors	A	B	C
Mating Mechanisms	A	B	C
Structural Seals	A	B	C

Notes:

(1) Includes valves, gages, transducers, etc.

(2) D = Major diameter of the seal.

(3) A = Interface shall have a minimum of two seals. The assembly shall be verifiable prior to launch.

Evidence of seal redundancy and proper seal installation shall be provided by monitoring the rate of tracer gas permeation in addition to verifying the total feedthrough steady state leakage rate.

(4) B = Interface shall have a minimum of two seals. Each seal shall be verifiable prior to launch and on orbit or during a planetary mission. Structural seals shall not be required to be verifiable during a mission.

The design shall include leak test ports and conductance grooves within the seal interstitial area to accommodate redundant seal verification

(5) C = Interface shall have a minimum of one seal. The assembly shall be verifiable prior to launch.

3.25 DECELERATION SYSTEMS

All deceleration devices will be considered structural systems and shall comply with the appropriate requirements contained within this document.

3.25.1 Special Considerations for Parachute Systems

All parachute system components shall maintain positive margins of safety using appropriate factors of safety, de-rating factors and material design allowables for all anticipated loading environments.

a) Minimum factors of safety for parachute system components are defined in Table 3.10-1.

b) The ultimate factor of safety for textile components of the parachute system shall be de-rated to account for the materials used, attachment methods and environmental conditions particular to the parachute design. NWC TP 6575, "Parachute Recovery Systems Design Manual" describes de-rating factors.

3.26 WIRE ROPE DESIGN REQUIREMENTS

The minimum ultimate factor of safety for wire rope used as part of a spacecraft structural system is given in Table 3.10-1.

3.27 FLUTTER

3.27.1 Classical Flutter

a) Constellation Program atmospheric flight vehicles shall be free from flutter at 1.32 times the maximum dynamic pressure expected at any point along the dispersed ascent, entry, and abort design trajectories with and without control surfaces activated.

b) The dynamic pressure margin shall be determined separately at constant density and at constant Mach number.

3.27.2 Stall Flutter

a) Separated aerodynamic-flow effects associated with lifting and stabilizing surfaces in high angle-of-attack maneuvers shall not result in structural failure or loss of control in Constellation Program atmospheric flight vehicles.

b) The vehicle shall be free of stall flutter at 1.32 times the dynamic pressure expected for this type of maneuver.

3.27.3 Panel Flutter

a) External surfaces shall be free of panel flutter at dynamic pressures up to 1.5 times the local dynamic pressure expected at any Mach number along the dispersed ascent, entry, and abort design trajectories;

b) The dynamic pressure margin shall be determined separately at constant density and at constant Mach number.

3.27.4 Control Surface Buzz

a) Constellation Program atmospheric flight vehicles, with or without control surfaces activated, shall be free of control surface buzz at dynamic pressures up to 1.32 times the maximum dynamic pressure expected at any point along the dispersed ascent, entry, and abort design trajectories.

b) The dynamic pressure margin shall be determined at constant density and at constant Mach number.

3.28 AEROELASTICITY

3.28.1 Static Aeroelasticity

3.28.1.1 Divergence

a) Constellation Program atmospheric flight vehicles shall be free from divergence at dynamic pressures up to 1.32 times the maximum dynamic pressure expected at any point along the dispersed ascent, descent, and abort trajectories with and without control surfaces activated.

b) The dynamic pressure margin shall be determined separately at constant density and at constant Mach number.

3.28.1.2 Aeroelastic Effects on Control Surfaces

Aeroelastic effects shall not reduce control surface authority below that which is required for vehicle control at all dynamic pressures and Mach numbers at any point along the dispersed ascent, entry and abort design trajectories.

3.28.2 Dynamic Aeroelasticity

Constellation Program vehicle flight structure shall be designed to prevent:

a) all detrimental instabilities due to coupled vibration modes;

b) detrimental loads and dynamic responses associated with structural flexibility; and

c) adverse interaction between the structure and other vehicle systems.

3.28.3 Vortex Shedding

Constellation Program vehicle flight structures shall be designed to prevent instabilities and excessive dynamic response due to vortex shedding produced by ground winds and gusts during both the pre-launch and launch phases.

3.28.4 Buffeting

Constellation Program flight vehicle structures shall be designed to prevent instabilities and detrimental dynamic response due to unsteady pressure loads in regions of flow separation or shock-boundary interactions, including the effects of high angle-of-attack and transonic Mach number environments at any point along the dispersed ascent, descent, and abort trajectories with and without control surfaces activated.

4.0 STRUCTURAL VERIFICATION REQUIREMENTS

Structural integrity shall be verified by inspection, analysis or test, or a combination of the three methods as described in CxP 70008, the Constellation Program Master Integration and Verification Plan (MIVP).

4.1 STRUCTURAL VERIFICATION PLAN

a) The organization responsible for structural design shall submit a detailed structural verification plan (SVP) for the flight hardware to NASA for Project and then Program approval.

b) The SVP shall include a requirements applicability matrix that identifies which paragraphs in section 3.0 of this document are applicable to the system or hardware being delivered.

c) The SVP shall identify the methods of structural verification for each hardware element.

d) The SVP shall identify the methods of verification for the structural and dynamic math models.

e) The SVP shall identify the proposed development, qualification and acceptance tests.

4.1.1 Structural Assessment After Critical Design Review (CDR)

Detailed verification planning and certification requirements need to be responsive to design and environment changes, even after CDR. Because of this requirement and the latest information technology, considered thought should be given to ideas such as automating the primary structure stress report.

The SVP shall identify the proposed methods of updating the hardware verification after CDR.

4.2 VERIFICATION OF DETAILED DESIGN CRITERIA

The responsible organization shall present any deviations to the design criteria identified in section 3.0 of this document as a waiver to NASA per paragraph 1.5.

4.3 STRENGTH AND STIFFNESS VERIFICATION

The responsible organization shall show by analyses and/or tests that the hardware meets Program design requirements and has the required strength, stiffness and integrity at the design temperature distribution to assure function and personnel safety.

4.3.1 Verification Tests

a) Strength verification of primary structure shall be by static test or appropriate dynamic strength test.

b) The responsible organization shall choose a test method from the three options provided in section 5.1, and provide verification test reports per section 5.3 of this document which will partially or completely verify the capability of the respective flight hardware to meet the design requirements specified herein.

c) Acceptance and qualification tests shall be performed to the appropriate test factor requirement(s) from Table 3.10-1 unless superseded by specific test factors identified in the verification requirements below or in the test requirements in section 5.0.

4.3.2 Verification Analyses

The responsible organization shall submit stress analyses per section 6.0 of this document which will verify the capability of the respective flight hardware to meet the design requirements specified herein.

4.4 MARGINS OF SAFETY VERIFICATION

a) The responsible organization shall deliver a detailed stress analysis report to NASA per section 6.0 of this document.

b) The stress analysis report shall contain a margin of safety summary table showing the minimum margin of safety for each and every part in the flight vehicle or element structure, the critical condition or mode of failure and the critical load for each and every part in the flight vehicle or element structure.

4.4.1 Yielding Verification

a) The stress analysis report (see section 6.0) shall identify any parts in which yielding will occur at limit load.

b) The structural integrity of the yielded component shall be demonstrated by analysis and/or test per section 5.0 and/or 6.0.

c) The functional integrity of the yielded component and/or system shall be demonstrated by analysis and/or test per section 5.0 and/or 6.0.

d) The service life of the yielded part shall be assessed by analysis and/or test per section 4.13, 5.0 and/or 6.0.

4.5 LOADS REPORTS

The requirements in section 3.5 shall be verified by analyses provided in the published reports, as described in Table 4.5-1, used to specify the design loads for the hardware.

Table 4.5-1 Verification for Development of Design Limit Loads

Published load reports shall be used to document the design loads and load spectra for the hardware.
Design loads releases shall support stress analysis delivery milestones as specified in section 6.2.3.
The responsible organization shall identify the version and modification history of the math models used in loads development.
The methodology and additional testing on the ground, in flight, on orbit, and on lunar/planetary operations required to validate the integrated system math models and design loads shall be developed and documented in the Structural Verification Plan.

4.5.1 Integrated Loads Verification

The loads, thermal environments and dynamic-elastic interactions between mated stages shall be verified by integrated analysis and/or test per the Constellation Program Structural Loads Control Plan, CxP 70137.

4.5.2 Design Loads Verification

The detailed design loads shall be verified by analysis provided in the published loads report per section 4.5, which shall show that the Loads Control Plan was properly implemented, and by any supporting ground or flight tests.

4.5.3 Verification for Redistributed Loads

This requirement shall be verified by analysis, test or both. Verification by test shall comply with section 5.0. The loads used shall be verified by analysis and/or test per the Constellation Program Structural Loads Control Plan, CxP 70137.

4.5.4 Verification for Friction Forces

Inspection of the stress analysis per section 6.0, and testing of the structure per section 5.0 as appropriate, shall verify that the structure meets this requirement.

4.6 VERIFICATION FOR BUCKLING AND CRIPPLING

a) Buckling and crippling integrity shall be verified by analysis, test or both per sections 5.0 and 6.0 of this document.

b) Evaluation of buckling strength shall consider the combined action of primary and secondary stresses and their effects on general instability, local or panel instability, and crippling.

c) Analyses of buckling of thin-walled shells shall use “knockdown factors” (correlation coefficients) to account for the difference between classical theory and empirical instability loads. Typical knockdown factors are listed in NASA SP-8007, Buckling of Thin-Walled Circular Cylinders

4.7 VERIFICATION FOR DYNAMIC INTERACTIONS

4.7.1 Verification of Dynamic Coupling

a) Freedom from undesirable interactions between the control system and the elastic vehicle modes shall be demonstrated by analysis using test verified structural math models per section 4.9.1.

b) This analysis shall account for the effect of engine thrust using models test-verified per section 4.9.1. If structural damping and stiffness cannot be verified for a given mission phase, then conservative values for both parameters shall be used.

4.7.2 Verification of Propellant Tanks Subject to Slosh Loads

a) These requirements shall be verified by analysis, test or both.

b) Analysis to characterize the extent of slosh shall account for tank characteristics, including size, geometry, internal hardware or structure, structural stability, internal insulation and venting provisions, liquid boiling, bubble entrapment, draining and settling, liquid level, fluid material compatibility and slosh frequencies, temperature and pressure variations and control system parameters.

c) Testing to verify the effects of slosh loads shall incorporate the agreed-to dynamic load considerations characteristic of the internal liquid during mission events.

4.7.3 Verification of Pogo Prevention

This requirement shall be verified by analysis as specified below.

4.7.3.1 Model Required for Pogo Verification

Coupling of the structure with the liquid-propulsion system shall be evaluated with the aid of a mathematical model that incorporates physical characteristics determined by tests and accounts for:

a) Elastic-mode coupling of the vehicle structure, propellant feed lines and tank-fluid system.

b) Engine Characteristics, including engine-mounting flexibility, turbo pump transfer functions, cavitation characteristics and propellant flow rates.

c) Delivery system characteristics, including flexible supports, accumulators, pressure-volume compensators, fluid or gas injection, fluid damping and flow resistances.

4.7.3.2 Stability Analysis for Pogo Verification

a) Stability analysis shall be performed using mathematical models to cover the entire rocket-powered flight regime.

b) Uncertainties in the parametric values shall be accounted for by appropriate statistical means for establishing that the probability of pogo instability during a space-vehicle flight is sufficiently small.

c) As a minimum requirement, the total coupled system shall be stable for any allowable combination of system parameter variations.

4.8 VERIFICATION OF THERMAL EFFECTS

Thermal effects shall be verified by analysis, test, or both.

4.9 MATH MODEL VERIFICATION

All static and dynamic math models that are used to develop design loads or to represent or certify individual or integrated Constellation Program flight vehicle structures shall be test validated.

These tests shall be performed at the flight vehicle level or at the component or subsystem level and the results combined.

4.9.1 Loads Model Verification

a) The loads model shall be verified according to the schedule in the Constellation Program Structural Loads Control Plan, CxP 70137.

b) The loads model shall be validated by modal survey testing to ensure the model is sufficiently accurate for load and deflection predictions. Other validation techniques may be used in certain situations with NASA approval per paragraph 1.5.

c) The modal survey test shall include appropriate techniques to identify nonlinearities and characterize their effects.

Model verification may be accomplished by a combination of spacecraft or element level and component level modal survey tests.

4.9.1.1 Resolution and Fidelity for Loads Analysis

a) The frequency range for load analyses, as determined by the resolution and fidelity of the integrated vehicle models and forcing functions, shall be supplied by the CxP.

b) The spacecraft, element or component dynamic model shall have sufficient fidelity to capture the subject's dynamic behavior in this frequency range.

c) Subsystem resonances and overall spacecraft, element or component modes shall be modeled up to a model upper bound frequency, which shall be at least 1.4 times the cutoff frequency of the load analysis.

4.9.1.2 Modal Survey Test Requirements

a) The modal survey test shall measure and correlate all significant modes below the model upper bound frequency, consistent with the model resolution requirement described in 4.9.1.1.

b) Significant modes may be selected based on an effective mass calculation, but this set should be augmented by modes which are critical for specific load or deflection definition.

c) Boundary interface degrees of freedom that carry loads in the flight configuration shall be constrained in verification testing. Other constraint conditions, such as free-free modal testing may be employed if there is sufficient technical rationale and the approach is approved by NASA per paragraph 1.5.

d) If alternate boundary conditions are utilized, additional testing and analysis shall be required to verify effects of the alternate configuration.

e) The test approach and technical rationale shall be provided in the structural verification plan.

4.9.1.3 Mass Representation in the Modal Test

Accurate mass representation of the test article shall be demonstrated with orthogonality checks using the analytical mass matrix $[M_A]$ and the test mode shapes $[ø_T]$.

- The orthogonality matrix is computed as $[ø_T]^T[M_A][ø_T]$.
- As a goal, the off-diagonal terms of the orthogonality matrix should be less than 0.1 for significant modes based on the diagonal terms normalized to 1.0.

4.9.1.4 Correlation Requirements for Loads Model Verification

Evidence of successful correlation between verification test data and the test article math model shall consist of frequency and mode shape comparisons.

a) Mode shape correlation shall be demonstrated qualitatively with mode shape descriptions and mode shape deflection plot comparisons.

- The **goal** for frequency correlation is less than ±5% differences on the significant modes and ±10% on higher order modes.

b) Quantitative mode shape comparisons shall be provided via cross-orthogonality checks using the test modes, the analytical modes, and the analytical mass matrix.

- diagonal terms greater than 0.9 is one **goal** for this cross-orthogonality check
- off-diagonal terms less than 0.1 for modes critical to the integrated interface loads and system internal loads is the other **goal**.

c) Failure to satisfy the goals of items (a) and (b) shall be accompanied by an assessment of the effects of model uncertainty on critical loads.

4.9.1.5 Simplified Loads Model Verification

Under certain conditions, simplified loads model verification by sinusoidal sweep test is allowed with approval from the appropriate Loads Control Panel.

a) The natural frequencies of the spacecraft, element or component shall be calculated with the flight configuration boundary conditions fixed.

b) Components with significant modes having a minimum frequency lower than or equal to the model upper bound frequency per paragraph 4.9.1.1 shall not use this simplified model verification method to verify the frequency.

c) If the simplified method is applicable, mode shape correlation is not required.

4.9.2 Stress Model Verification

If all verification conditions will not be achieved by test, and the analysis-only approach described in section 3.10.3 has not been approved, the stress model shall meet the following requirements:

a) Testing for static model verification shall include full-scale testing to loads sufficient to achieve a limit condition, and limited subassembly qualification testing as appropriate.

b) Deflection and strain data taken during static tests shall be compared with model predictions through the entire load range.

c) Checks shall be made for linearity and correlation to prediction.

1. Models shall correlate to test within 10% of predicted values for salient deflections.

2. Models shall correlate to test within 0% - 10% of predicted values for salient strains, with any deviations being model predictions higher than test results.

3. If the math model predictions are outside the above stated correlation criteria, the math model shall be updated until it meets the criteria and the analysis re-run.

4. A model that analytically under predicts stress shall be corrected and/or margins of safety recalculated based upon test stress levels.

4.9.3 Thermal Math Model Verification

The math models used to predict structural design temperature distributions shall be validated using test data, as appropriate, to minimize uncertainties in structurally sensitive areas.

4.10 VERIFICATION OF MINIMUM FACTORS OF SAFETY

The stress analysis report provided per section 6.0 shall contain a margin of safety summary table showing the factor(s) of safety used in analyzing each and every part in the flight vehicle structure. Inspection of this report shall verify that the factors of safety used in the design and analysis of the hardware meet the specifications of section 3.10.

4.11 VERIFICATION OF MATERIALS

4.11.1 Verification of Material Thickness for Design and Analysis

The stress analysis report shall clearly identify the dimensions of the part being analyzed and shall compare these dimensions to the drawing dimensions for the part.

4.11.2 Verification of Material Properties

a) The stress analysis report shall provide a reference for any material property data used in the analysis.

b) If NASA approval was required for use of certain material properties, the approval documentation shall be included in the stress analysis report.

c) If the “premium properties” option described in 3.11.2(d) is chosen, a materials test report shall be provided for each produced part which justifies the design allowables developed through the material lot specific testing along with the stress analysis report for each part designed and certified to these properties.

d) The stress analysis report shall clearly identify which parts are single load path.

4.11.3 Verification of Material Creep Susceptibility

a) The material selection shall be verified by inspection of the stress analysis report.

b) If the part will experience creep during its service life, creep susceptibility shall be characterized by test.

4.11.4 Verification for Castings

Verification for castings (such as material property and fracture control verifications, among others) is contained in other program-imposed requirement and verification documents as discussed in paragraph 1.2.

4.12 DESIGN FACTOR VERIFICATION

The stress analysis report per section 6.0 shall identify all of the design factors used in the analysis of every part. Inspection of this report shall verify that the factors used in the design and analysis of the hardware meet the specifications of 3.12.

4.13 VERIFICATION OF STRUCTURAL LIFE

a) Structural service life shall be verified by analysis and/or test based on a rationally derived cyclic loading spectrum that includes transport to and from orbit, on-orbit, lunar or planetary mission events, thermal stresses, ground transportation, and testing loads.

b) The responsible organizations shall identify the specific analytical approach for life verification for cyclic and sustained loads in the design environment, which includes atomic oxygen, radiation, plasma environmental effects incompatibilities, debris, and meteoroid environments as defined in CxP 70023, the Design Specification for Natural Environments.

c) The service life capability of all non-fracture critical structural parts shall be verified. This verification may be accomplished by one of the following analytical methods listed below.

    1. Stress-life (S-N fatigue).
    2. Strain-life (e-N).
    3. Durability (e.g., fracture mechanics for metallic parts and damage mechanics for composite parts)

d) The service life analysis loading spectrum shall include at least one limit load cycle (factor of safety = 1.0)

e) For components whose design is subject to a cyclic or repeated load condition, or a randomly varying load condition, a cyclic life analysis shall be performed.

f) Temperature distributions shall be included in the structural life assessment.

4.13.1 Verification of Service Life Considering Cumulative Damage

4.13.1.1 Fatigue Verification

In the fatigue analysis, the limit stress/strain shall be multiplied by a minimum factor of 1.15 on typical fatigue properties or 1.0 on lower bound fatigue properties prior to entering the stress versus cycle life (S/N) design curve to determine the low-cycle and high-cycle fatigue life. (Note: NASA-STD-5019, paragraph 4.1.1.12 defines a low risk part, and provides requirements for fatigue analysis of these parts, including a 1.5 factor on alternating stress. The 1.15 factor in this CxP 70135 paragraph is not used if the part is low-risk per NASA-STD-5019, paragraph 4.1.1.12. The alternating stress is just multiplied by 1.5 for low-risk parts).

4.13.1.1.1 Life Cycle History

A design-life cycle history shall be developed in sufficient detail that a cumulative damage assessment can be analytically verified for all applicable components. In general, these data can be shown by a component load history profile including usage cycles, load intensities and environments.

4.13.1.1.2 Low Cycle Fatigue Analysis

For low cycle fatigue analysis, the minimum number of cycles used shall be 1000.

4.13.1.1.3 Method Selection for Combining Damage

a) For cyclic loads to varying levels, such standard methods as Miner's Method shall be used to determine the combined damage.

b) For repeated load combined with a steady load, such standard methods as the Modified Goodman Diagram shall be used to determine the combined effect.

c) The cycle counting approach for random load spectrums shall use such standard methods as Rainflow Counting.

4.13.1.1.4 Stress Concentration Factors – Fatigue Analysis

The alternating and mean stress/strain analyses shall include the effects of stress concentration factors when applicable.

4.13.1.2 Durability Analysis

Durability analysis for life verification of metallic parts shall be performed according to one of the following options:

- Option A
  - A flaw of 0.005-inch radius at the worst case location and orientation in the part for metallic materials shall be assumed.
  - A factor of 1.5 on alternating stress shall be used.
  - A scatter factor of 4 on life shall be used in the analysis.
- Option B
  - NDI inspection per NASA-STD-5009 shall be performed on the metallic part. If a crack is found, it shall be removed or repaired. If removal or repair is not feasible, use of hardware with known cracks shall be approved by the responsible technical authority
  - A factor of 1.0 on alternating stress shall be used.
  - A scatter factor of 2 on life from the initial crack size defined by NASA-STD-5009 or the results of the NDI, whichever is larger shall be used.
  - In the analysis, the initial crack shall be placed in the worst case location and worst case orientation within the part.
  - Mandatory NDI inspection every 1/8 of the design service life or at other intervals determined by the responsible technical authority shall be performed.

4.13.2 Verification of Creep Life

a) Creep life requirements shall be verified by analysis.

b) All structural components subject to combined fatigue and creep shall be evaluated using standard methods such as Miner's accumulated damage procedure for final life predictions.

c) The limit stress/strain shall be multiplied by a minimum factor of 1.15 prior to entering the design curve to determine creep life.

4.14 VERIFICATION OF BERYLLIUM STRUCTURES

4.14.1 Identification of Beryllium Structures

a) All beryllium structures shall be reported to NASA by component identification, part identification (drawing number) and beryllium alloy. The only beryllium alloys exempt from this review are those where beryllium is a minor constituent (less than 4 percent) such as copper-beryllium, nickel-beryllium and the beryllium-oxide ceramics.

b) Drawings of both the part and the component shall be submitted to NASA to aid in identifying the beryllium part location and its function.

4.14.2 Verification Documentation for Beryllium Structures

4.14.2.1 Internal Loads Analysis for Beryllium Structures

A formal internal loads analysis shall be submitted to NASA for review that includes appropriate boundary conditions, external load application locations, bounded static and dynamic loads used for design, distortions and forces that affect the short transverse (through the thickness) direction stresses and thermal loads.

4.14.2.2 Stress Analysis for Beryllium Structures

a) A formal stress analysis shall be submitted for review per section 6.0.

b) The formal stress analysis shall be in sufficient detail to address the effects of elastic stress concentrations, tolerances and displacements that may occur in the short transverse direction of the beryllium material.

4.14.3 Manufacturing Process Requirements for Beryllium Structures

Manufacturing and material processes for beryllium hardware shall be subject to NASA approval per paragraph 1.5. The following requirements must be included in the process specifications:

1) Machined/mechanically disturbed surfaces of a structural beryllium part must be chemically milled to ensure removal of surface damage.

2) All beryllium parts must be penetrant inspected for crack like flaws with a high sensitivity fluorescent penetrant per ASTM E1417-95a.

Fracture control requirements for beryllium parts are contained in other program documents, as described in paragraph 1.2.

4.14.4 Verification Testing of Beryllium Structures

The structural verification of beryllium structures shall comply with one of the following three options:

1. For two or more beryllium parts of the same design and geometry which are both produced by the same manufacturer using identical materials and process specifications, a verification test program shall be implemented.

    a) This test program shall demonstrate the ultimate load carrying capability of the part by statically testing one of the parts to a minimum of 1.4 times the maximum limit load. This test may be performed on a dedicated test article if the article is made by the same manufacturer using the same material and process specifications as the flight hardware. Otherwise, one of the flight articles must be used.

    b) There shall be no failures.

    c) A detailed, post-test inspection of the hardware shall be performed to ensure its structural integrity prior to flight if a flight article is used for testing.

    d) The remaining flight articles shall be proof-tested to the limit load.

    e) The test article used for the 1.4 times limit load test shall include all possible sources of out-of-plane loading that may occur from the assembly of the beryllium part or installation of the beryllium part into the spacecraft. This includes the effects of attachments and out-of-plane loading from clamp-up, fastener torque, shims, etc.

    f) For those areas of the beryllium part where the failure criteria are not well-defined, sufficient testing of these regions shall be performed to establish confidence in the stress analysis.

    g) For beryllium structures that are subjected to buckling loads, ultimate loads testing shall be performed to demonstrate a minimum buckling margin of safety of 10 percent (based on 1.4 times the part limit load).

2. For beryllium parts that are one of a kind, with no dedicated test article, a comprehensive ultimate load test shall be implemented in which the flight article is subjected to a minimum loading of 1.4 times limit load.

    a) The requirements for this testing shall be per Option 1.

    b) In addition, a complete and detailed structural inspection of the tested structure shall be performed to ensure the integrity of the tested structure prior to flight.

3. Other combinations of criteria and or testing that are equivalent to those above must be submitted to NASA for approval per paragraph 1.5.

4.15 VERIFICATION OF LIQUID FUELED SPACE PROPULSION SYSTEM STRUCTURES

Verification of structural components of liquid fueled space propulsion system engines shall comply with NASA-STD-5012, Strength and Life Assessment Requirements for Liquid Fueled Space Propulsion System Engines.

4.16 COMPOSITES/BONDED STRUCTURE VERIFICATION

4.16.1 General Verification Requirements

a) Composite/bonded structural design shall be verified by a combination of analysis, test and inspection.

b) Test articles shall be designed and fabricated to the same requirements, drawings and specifications as the flight article.

4.16.1.1 Structural Analysis for Composite/Bonded Structural Verification

a) Structural analysis per Section 6.0 shall contain a margin of safety summary table showing the factor(s) of safety used in analyzing each composite/bonded part in the flight vehicle structure.

b) Inspection of this report shall verify that the factors of safety used in the design and analysis of the hardware meet the specifications of section 3.10.

4.16.2 Acceptance of Composite/Bonded Structure

Acceptance of composite/bonded structures shall be by one of the following methods. Acceptance proof test factors for composite/bonded structures are given in Table 3.10-1.

4.16.2.1 Acceptance Proof Test

An acceptance proof test shall be conducted to no less than 120 percent of the limit load.

a) The proof test shall be conducted on each composite/bonded flight article.

b) Test loads on the composite shall not exceed 80 percent of the composite/bonded material ultimate strength. (The testing shall be limited to 80 percent of the composite/bonded material ultimate strength if testing to 120 percent of limit load exceeds this threshold).

c) The flight article shall receive pre- and post-proof test NDE including special visual inspection per MSFC-RQMT-3479, Section 6.1.

d) The flight article shall be subject to a Damage Threat Assessment per MSFC-RQMT-3479, Section 5.3.2.1.

e) The test may be accomplished at the component or subassembly level if the loads on the test article duplicate those in a fully assembled test article.

f) No detrimental deformation to any metallic fittings and fasteners in the flight assembly or damage to the composite shall occur during the acceptance proof test.

4.16.2.2 Acceptance by Demonstration of Successful History

Composite hardware other than pressure vessels, propellant tanks or solid rocket motor casings, may be accepted without proof test if prior NASA approval of this approach is granted before implementation per Paragraph 1.5.

This approval shall be based on NASA concurrence with a written risk assessment and supporting rationale that an acceptable level of safety and verification of structural integrity is maintained. This rationale shall include, but is not necessarily limited to:

1. Material characterization is established to the necessary statistical level.
2. All other applicable strength, stiffness and structural life requirements of this document are verified.
3. Certified and controlled process specifications are used that have been demonstrated to establish the necessary level of manufacturing process control.
4. Manufacturing and inspection personnel are properly trained and certified; and,
5. Proposed non-destructive inspection techniques have the necessary detection capability to establish appropriate quality assurance and controls for manufacturing defects.

This option shall be supported by documentation demonstrating compliance with the listed criteria and approved by NASA per Paragraph 1.5. Proposals for this approach shall be submitted for review no later than the Preliminary Design Review.

4.16.2.3 Acceptance by Damage Tolerance Approach

Composite structures may be accepted using a damage tolerance approach that shall comply with the requirements of MSFC-RQMT-3479, Paragraph 5.3.2.

4.16.2.4 Verification of Design and Analysis Practices for Composite/Bonded Structure

a) The designer/manufacturer shall report all standards used in the design and manufacturing process for the composite or bonded structure.

b) The verification data package shall include summary reports of all coupon tests, sampling techniques and development testing used in the design and manufacturing of the composite or bonded structure.

c) The verification data package shall include all documentation as required by MSFC-RQMT-3479, Section 7.0.

4.16.3 Verification of Composite Structure Protection Against Inadvertent Damage

The damage protection plan for composite structure shall be verified by inspection per MSFC-RQMT-3479, Section 5.3.2.2.

4.16.4 Composite/Bonded Structure Life Verification

The required life for a composite/bonded structure shall be demonstrated by durability testing or a combination of testing and analysis. Guidance for durability and structural life verification for composite/bonded structure is provided in MIL-HDBK-17-3F, Composite Materials Handbook.

4.16.4.1 Flaw Growth Rate for Composite/Bonded Structure Life Verification

The growth rate or no-growth of damage that may occur from fatigue, corrosion, manufacturing flaws or impact damage under repeated loads expected in service for composite/bonded structure shall be established by test or analysis supported by test.

4.16.4.2 Damage Growth For Residual Strength of Composite/Bonded Hardware

The damage growth between initial detectability and the value selected for residual strength testing of composite/bonded hardware, factored to obtain inspection intervals, shall allow for development of an inspection program.

4.16.4.3 Strength Verification for Composite Structures for which Damage Tolerance is Impractical

a) Composite/bonded structural components for which the damage tolerance method is shown to be impractical shall be verified by component fatigue tests or analysis supported by tests to be able to withstand the repeated loads of variable magnitude expected in service.

b) Sufficient component, subcomponent, element or coupon tests shall be performed to establish the fatigue scatter factor and any environmental effects on the structural life.

c) Damage up to the threshold of detectability and ultimate load residual strength capability shall be considered in the testing and analysis.

4.16.5 Special Considerations for Bonded Joints

4.16.5.1 Limit Load Capability Verification of Bonded Joints

For any bonded joint, the failure of which would pose a catastrophic hazard, the limit load capacity shall be substantiated by one of the following methods:

1. The maximum disbonds of each bonded joint consistent with the capability to withstand the required loads shall be determined by analysis, tests or both. Disbonds of each bonded joint greater than these values shall be prevented by design.
2. Proof testing shall be conducted on each production article that will apply the critical limit design load to each critical bonded joint.
3. Repeatable and reliable non-destructive inspection shall be established and periodic inspections shall be performed that ensure the strength of each bonded joint.

4.16.5.2 Environmental Effects on Bonded Joints

All proof testing to confirm the capability of bonded joints shall be performed in the appropriate environment or a test-verified environmental correction factor (ECF) shall be used.

4.17 STRUCTURAL VERIFICATION FOR PRESSURE SYSTEMS

4.17.1 Structural Verification of Pressurized Systems

a) Pressurized systems shall be verified by analysis and test as specified in the latest revision of Aerospace Report No. TOR-2003 (8583)-2896, Space Systems – Flight Pressurized Systems, as tailored herein.

   Note: This TOR is a draft version of a proposed standard ANSI/AIAA S-087.

b) Constellation Program loads and environments shall be verified as per paragraph 4.5 in place of loads and environments verifications specified in standards.

4.17.2 Verification of Factor of Safety Requirements for Pressurized Hardware

Pressurized hardware shall be verified by test per section 5.2.3 and analysis per section 6.0 with the pressure used identified in the reports. Required test factors for acceptance and qualification are given in Table 3.10-1.

4.17.3 Verification of Design Pressure

The pressure used in the verification of pressurized hardware shall be identified in all verification reports. Rationale and approval shall be documented if MEOP is used.

4.17.4 Verification of Fracture Control for Pressurized Hardware

Fracture control of Constellation Program pressurized hardware is specified in other program-imposed requirement and verification documents as discussed in paragraph 1.2.

4.17.5 Verification Requirements for Pressure Vessels, Pressurized Structures, and Sealed Containers

a) Dimensional stability of pressure vessels shall be verified by test per section 5.0 and/or analysis per section 6.0.

b) Pressure vessel qualification testing shall include a burst test to failure following a successful design burst pressure test performed per paragraph 5.2.3.2.

4.17.5.1 Structural Verification of Metallic Pressure Vessels, Sealed Containers and Pressurized Structures

Metallic pressure vessels and pressurized structures shall be verified by analysis and test as specified in the most recent revision of ANSI/AIAA-S-080 and tailored herein.

4.17.5.2 Structural Verification Requirements for COPVs

COPVs shall be verified by analysis and test as specified in the most recent revision of ANSI/AIAA-S-081 and tailored herein.

4.17.6 Structural Verification of Pressurized Lines, Fitting, and Other Pressurized System Components

Pressurized lines, fittings and components shall be analyzed and tested as specified in the most recent revision of ANSI/AIAA-S-080 and tailored herein.

Qualification burst testing is not required for: 1) lines and 2) standard fittings procured to commercial standards and specifications. Qualification burst testing is required for non-standard, specialized, or customized fittings.

4.17.6.1 Verification of Restraints for Pressurized Lines or Flexible Hoses

a) Verification that pressurized lines or flexible hoses are restrained or captured shall be by inspection.

b) Verification that the restraints prevent whipping of the hose or line end shall be by analysis per section 6.0.

c) The strength of the restraints shall be verified by analysis per section 6.0.

4.17.6.2 Verification of Safe Disconnect for Pressurized Connections

Safe venting of pressurized connectors shall be verified by analysis. The analysis shall identify design features that allow depressurization before disconnection of connectors.

4.17.7 Structural Verification for Habitable Modules

Structural verification of habitable modules shall be by test per section 5.2.3 and analysis per section 6.0.

4.17.7.1 Verification for Doors and Hatches in Habitable Modules

Structural verification for doors and/or hatches in habitable modules shall be verified by test per section 5.0 or analysis per section 6.0 in both the closed and open positions for both ground and space environments.

4.17.7.2 Verification of Dimensional Stability for Habitable Modules

Dimensional stability of habitable modules shall be verified by test per section 5.0 and/or analysis per section 6.0.

4.17.8 Verification of Negative Pressure Capability

The capability of pressure system components to sustain the required negative pressure differential shall be verified by test or analysis.

4.17.8.1 Verification of Negative Pressure Damage Prevention for Pressure Vessels

Verification of negative pressure damage prevention shall be by analysis and inspection.

a) A system analysis shall be performed to identify any negative pressure environment that could cause damage to the pressure vessel.

b) An inspection of the quality records shall be performed to show that the appropriate tagging, procedures, or protective devices have been implemented to protect the pressure vessels from the identified negative pressure environments.

4.17.9 Verification of Pressure Control Devices

Pressure control devices shall be verified by analysis and inspection of design documentation to ensure they are collectively two-fault tolerant in controlling the pressure from exceeding the MDP of the system.

4.17.10 Verification of Pressure-Stabilized Structures

a) Structures which are pressure-stabilized and must contain a minimum pressure to maintain the required ultimate factors of safety to insure structural integrity under all load combinations shall meet all of the verification requirements for pressurized structure in section 4.17.

b) Pressure verification in a pressure-stabilized structure shall include a pressure decay monitoring technique which is implemented such that the system pressure decay characteristics can be certified to insure minimum design safety factors will exist at the time of subsequent structural load application.

4.17.11 Burst Disc Verification

a) The burst disc design configuration shall be verified by inspection of drawings and specifications to confirm that 3.17.11 (a) and (b) are met.

b) The burst disc design shall be qualified for the intended application by testing at the intended use conditions including temperature and flow rate.

c) Qualification shall be for the specific part number used, and it shall be verified that no design or material changes exist between flight assemblies and assemblies making up the qualification database.

d) Each flight assembly shall be verified for membrane actuation pressure either by

   1. Use of special tooling or procedures to prevent cutting edge contact during the test.

   2. Demonstration of a rigorous lot screening program approved by NASA per paragraph 1.5.

4.17.12 Verification of Dewars

a) Structural verification of dewars shall be performed per paragraph 4.17.5 with the following qualifiers on testing:

   1. The proof test factor for each flight pressure container shall be a minimum of 1.1 times the design pressure determined in paragraph 3.17.12 (a).

   2. Qualification burst and pressure cycle testing is not required if all the requirements of paragraphs 3.17.12 and 4.17.12 (b) through (f) are met, and if fracture control does not require qualification or pressure cycle testing.

b) The pressure relief capability of the outer shell shall be verified by an analysis and/or test. The analysis and/or test shall ensure that the outer shell pressure does not exceed its design pressure.

c) The outer shell pressure relief device venting rate shall be verified by an analysis and/or test. The analysis and/or test shall ensure that the MDP for the outer shell envelops the worst-case pressure achieved under maximum venting conditions.

d) Redundancy of the relief devices shall be verified by inspection of the drawings and device specifications. The inspection shall ensure relief-device redundancy and the sufficiency of individual relief devices to maintain the pressure container or outer shell pressure below their respective maximum design pressures.

e) Certification of the pressure relief device shall include testing of the same part number from the flight lot under the expected use conditions.

f) Non-hazardous fluid vent shall be verified by analysis. The analysis shall ensure that the vented fluids which could be released into the inter-element volume do not detrimentally affect Constellation Program hardware structural integrity or thermal capability and are not a catastrophic hazard due to factors such as, but not limited to: atmospheric pressure or temperature, touch temperature, toxicity, flammability, fluid concentration levels in the cabin atmosphere, or fluid incompatibility with cabin atmospheric filtering.

4.17.13 Secondary Volume Verification

The structural integrity of secondary compartments or volumes attached by design to pressure system components that can become pressurized as a result of a credible single barrier failure in the pressure system component shall be verified by analysis per section 6.0 showing positive margins of safety for 1.5 x MDP.

4.17.13.1 Verification of Allowable Venting for a Secondary Pressurized Volume

If the secondary pressurized volume is vented with a pressure relief device, this requirement shall be verified by

a) Inspection of pertinent vent or relief device drawings or specifications and

b) Analysis per section 4.17.12 (f) or test.

4.17.13.2 Verification for Credible Failures in a Secondary Pressurized Volume

The elimination of credible single barrier failures shall be verified by analysis and/or test. For items described in 3.17.13.2 (c), the requirement is verified by analysis, by manufacturing inspections performed to program-imposed inspection requirement and verification documents and by leak tests at operating pressure.

4.17.14 Verification of Hoses And Bellows Subject to Flow-Induced Vibration

a) Certification of hardware shall be in accordance with NSTS 08123, Certification of Flexhoses and Bellows for Flow Induced Vibration.

b) When certification by test is required, requirements in MSFC-SPEC-626, Test Control Document for Assessment of Flexible Lines for Flow Induced Vibration shall apply.

4.18 STRUCTURAL VERIFICATION REQUIREMENTS FOR ROTATING MACHINERY

The hazard analysis of any equipment that contains rotating parts shall verify the failure modes and hazard potential of the equipment.

4.18.1 Design Loads Verification for Rotating Machinery

a) Design loads for rotating machines shall be verified by analysis at the designated technical authority.

b) The stress analysis report shall identify all load cases considered, including the self-induced loads.

4.18.1.1 Rotor Dynamics Verification

a) Critical speeds shall be verified by analysis and test demonstrating that there are no deleterious effects on the safety and operation of the rotating machinery system.

b) Frequency margins shall be verified by analysis and documented in a report.

4.18.1.2 Rotating Machinery Stability Verification

The stability of rotating parts shall be verified by analysis and/or test. Stability margins shall be documented in a report.

4.18.2 Strength Verification for Rotating Machinery

The strength of rotating parts shall be verified by test per paragraph 5.2.4 and/or analysis per section 6.0, demonstrating that all margins of safety are greater than or equal to 0.0 and that the factors of safety from Table 3.10-1 were properly applied.

4.18.3 Fatigue Verification for Rotating Machinery

These requirements shall be verified by analysis and/or test per section 4.13 and the detailed requirements in this section. The durability approach is not permitted for rotating machinery components.

4.18.3.1 Fatigue Analysis Requirements

The fatigue analysis for rotating machinery shall be consistent with section 4.13.1.1 with the exception of the following:

a) In the fatigue analysis for rotating machinery, the limit stress/strain shall be multiplied by the Fatigue Analysis Factor (FAF) prior to entering the S-N design curve to determine the low-cycle/high-cycle life. The FAF shall be

   1. FAF = 1.25 Rotating components

2. FAF = 1.15 Non-rotating components

b) There is no minimum requirement for number of cycles in low-cycle fatigue for rotating machinery.

4.18.3.2 Fatigue Tests

If all verification requirements for fatigue will not be achieved by analysis, fatigue tests are required. These tests are conducted on flight-configured hardware in the appropriate environment and shall be specified in the SVP.

4.19 VERIFICATION OF STRUCTURAL SOFT GOODS

Structural soft goods shall be verified by acceptance tests and qualification tests per section 5.0. Test factors for acceptance and qualification of structural soft goods (excluding parachutes and parafoils) are given in Table 3.10-1 (C).

4.20 VERIFICATION FOR THE CSSE AND VIE

This requirement shall be verified by test per the CSSE SRD or VIE SRD.

4.21 VERIFICATION OF STRUCTURAL INTEGRITY IN THE SPACE ENVIRONMENT

4.21.1 Structural Verification After General Material Erosion

The effect of structural degradation from material erosion shall be verified by analysis, test or both. The analysis and/or test shall include the effects of Plasma Environmental Effects, atomic oxygen, and other natural environments over the design life of the structure.

4.21.2 Structural Verification After MM/OD Impact Damage

This requirement shall be verified by a probability-of-no-penetration (PNP) analysis supported by hypervelocity impact test data to show that MM/OD critical items meet the requirements specified in the appropriate CxP SRD’s.

4.21.3 Structural Verification After EVA Crew Inadvertent Contact

This requirement shall be verified by test per section 5.0 and/or analysis per section 6.0 demonstrating the performance requirements are met after exposure to EVA crew inadvertent contact loads.

4.21.4 Structural Verification After IVA Crew Inadvertent Contact

This requirement shall be verified by test per section 5.0 and/or analysis per section 6.0 demonstrating the performance requirements are met after exposure to IVA crew inadvertent contact loads.

4.22 SECONDARY STRUCTURE VERIFICATION

These requirements shall be verified by inspection of installation drawings, analysis, and/or test.

4.23 VERIFICATION OF FASTENERS AND JOINTS

4.23.1 Verification of Fastened Joints

The fastener requirements documented in NASA-STD-6008, NASA Fastener Integrity shall be verified by inspection of Quality records, drawings, installation procedures, analysis and vendor data.

4.23.1.1 Verification of Structural Fastener Retention

Locking feature installation shall be verified by inspection of the installation procedures and the Quality records for the hardware being delivered.

a) The location of the locking feature shall be verified by inspection of the relevant installation drawing(s).

b) Installation procedures shall require functional verification of locking features, such as measurement of running (self-locking) torque or visual inspection of lock wire integrity to be performed and recorded for each individual structural fastener.

4.23.1.1.1 Fastener Retention Redundancy

a) Fastener retention redundancy shall be verified by inspection of the relevant installation drawing(s).

b) If preload is used as one of the locking features, the preload shall be verified by analysis per paragraph 4.23.1.8.

4.23.1.1.2 Verification for Structural Fasteners in Rotating Joints

The retention feature utilized for a structural fastener in a rotating joint shall be verified by inspection of the relevant installation drawing(s).

4.23.1.1.3 Verification of Snap Rings and Cotter Pins

These requirements shall be verified by inspection of the Quality records delivered with the hardware.

4.23.1.2 Verification of Fastener Torque Specification

a) The specified torque value shall be verified by inspection of the fastener specification and the relevant installation drawing(s) and the Quality records for the hardware being delivered.

b) Torque-tension testing shall be required for the following applications:

1. Where fastener/lubricant combination friction factor (k) values are unknown,
2. Where the failure of a single bolt in a tension application would cause a critical or catastrophic hazard or functional problem.

c) Torque tables that are used to establish torques shall be based on torque-tension testing data using the same fastener/fitting combinations to be used in flight, including washers.

d) The data used to create the tables shall be made available to NASA upon request.

e) Proper torque specification for fasteners assembled and disassembled by the flight crew shall be verified by analysis and inspection of the procedures.

4.23.1.2.1 Verification of Torque Application

This requirement shall be verified by inspection of the relevant installation drawing(s) and procedures and the Quality records for the hardware being delivered.

4.23.1.2.2 Running Torque Verification

Verification shall be by inspection of the relevant installation drawing(s) and the Quality records for the hardware being delivered.

4.23.1.2.3 Wrenching Torque Verification

Verification that the design torque value does not exceed the wrenching torque value shall be accomplished by inspection of the fastener specification and the relevant installation drawing(s), procedures and the Quality records for the hardware being delivered.

4.23.1.3 Verification of Inserts

Appropriate use of inserts shall be verified by inspection of the relevant installation drawing(s) supplemented by either a detailed grip measurement during installation or a tolerance stack-up analysis assuring proper installation will be achieved.

4.23.1.4 Verification of Thread Engagement

This requirement shall be verified by inspection of the relevant installation drawing(s).

4.23.1.5 Grip Length Verification

a) The grip length specification and the use of washers shall be verified by inspection of the appropriate installation drawing(s) and procedures.

b) Torque-tension tests per paragraph 3.23.1.2 shall be performed to verify the use of washers in joint fit-up if applicable.

4.23.1.6 Verification for Strength Issues in Fastener Specifications

These requirements shall be verified by inspection of the relevant installation drawing(s), Quality records and by analysis.

4.23.1.7 Verification Of Thread Specification

Thread specification shall be verified by inspection of the relevant installation drawing(s) and fastener procurement specification(s) to ensure compliance with thread form requirements.

4.23.1.8 Preload Verification

This requirement shall be verified by analysis and test, with additional testing possibly required to specifically satisfy the specifications in NSTS-08307.

a) If the conditions in paragraph 3.23.1.8 are satisfied, then the fastener margin of safety shall be assessed in the gapped condition in the usual manner for interacting shear, bending, and tension, as applicable, with the tension portion of the interaction calculated using the applied tensile load.

b) If the conditions in paragraph 3.23.1.8 are not met, and the joint has been designed using NSTS-08307, then the preload verification shall be per NSTS-08307.

c) Structural analysis of preloaded joints shall show a joint separation factor of 1.4 for safety critical joints and 1.2 for other joints.

d) Preloaded joints which contain pressure seals where gapping or failure may pose a catastrophic hazard shall demonstrate no gapping in a qualification test or acceptance test at combined limit loads and limit pressure.

4.23.1.9 Verification of Nonstandard Fasteners

Verification of nonstandard fasteners shall comply with section 4.23.1.

4.23.1.10 Verification of the clamping of soft goods.

The preload application and variation over time in a joint that includes the clamping of soft goods shall be verified by test. This testing shall support the specification of torque checks intervals for this type of joint to ensure no detrimental loss of preload.

4.23.2 Strength and Structural Life Verification of Welded Joints

Structural verification of welded joints and joint repairs shall be by inspection, test per section 5.0, and analysis per section 6.0. Material properties used in welded joint design will be documented according to other program requirements found in paragraph 1.2.

In addition to the specific inspections noted below, the following inspections shall be performed to verify the requirements in paragraph 3.23.2 are met:

a) Inspection of the weld process and weld repair specifications,

b) Inspection of the weld qualification test plans for the welded joint configurations,

c) Inspection of the engineering drawings of the hardware,

d) Inspection of the quality records for the weld inspections.

4.23.2.1 Verification of Design Allowables for Welded Joints

Inspection of the strength and structural life analysis reports and materials test reports shall verify that the appropriate material properties test data was used to develop design allowables for the specific joint configuration.

4.23.2.1.1 Verification of Acceptable Dimensional Variations for Welded Joints

a) The strength and structural life analysis and testing shall account for the acceptable dimensional variations of the joint specified on the engineering drawings.

b) The strength and structural life analysis and testing of welded joints shall consider the effects of both stress concentration factors and residual stresses resulting from the welding and weld repair process.

4.23.2.1.2 Verification of NDE for Welded Joints

The strength and structural life analysis and testing shall account for the sensitivity of the non-destructive evaluation method specified on the engineering drawings.

4.23.2.2 Verification of Drawing Specifications for Welded Joints

The drawing specifications for welded joints and joint repairs shall be verified by inspection of the relevant drawings and structural analysis and test reports.

4.24 VERIFICATION OF SEAL REDUNDANCY

Seal redundancy shall be verified by inspection, analysis and test per Table 3.24-1 and the following acceptance and qualification tests as appropriate. When verification by test is required, an appropriate method shall be used per the leak test provisions in CxP 70036, Constellation Program Environmental Qualification and Acceptance Testing Requirements (CEQATR).

4.24.1 Seals with Major Diameter less than or equal to Six Inches

a) For seals with major diameter of less than 6 inches, qualification and acceptance testing of the permanent installation shall be conducted to verify the sealing capability of the seal assembly.

b) The qualification testing shall include structural deflections, pressure differential and thermal and dynamic effects as appropriate.

4.24.2 Seals with Major Diameter Greater Than Six Inches

a) For seals with major diameter of greater than or equal to six inches, qualification and acceptance testing of the permanent installation shall be conducted to verify the sealing capability of each seal.

b) The qualification testing shall include structural deflections, pressure differential and thermal and dynamic effects as appropriate.

c) Qualification demonstration in a 1g environment shall be conducted to verify that each seal can be verified on-orbit for those seals notes as “B” in Table 3.24-1.

d) Qualification analysis shall be conducted to extrapolate the 1g demonstration to a 0g environment.

4.25 VERIFICATION OF DECELERATION SYSTEMS

Deceleration system design requirements shall be verified by analysis, test or both. The system provider shall provide the details of the structural verification methods to be used in the Structural Verification Plan (SVP) for approval by NASA per paragraph 1.5.

4.25.1 Verification Requirements for Parachute Systems

a) The system SVP shall include a detailed structural verification section for the parachute system describing the component and system development, qualification and acceptance testing required to verify the structural margins of all system components.

b) The plan shall contain at a minimum:

1. The proposed development, qualification and acceptance tests for both the parachute system and its components, including pull tests of all critical textile-to-textile and textile-to-mechanical joints.
2. The number and description of full-scale instrumented canopy tests including test environments and load conditions.
3. The number and description of canopy re-use tests to verify the de-rating factors used in the structural analysis and the allowable number of re-uses of the canopy.
4. The methods of verification for any structural, dynamic or aerodynamic math models used to certify the structural performance of the parachute system.

c) The stress report shall include all test data and assumptions used to develop the material design allowables, factors of safety, design loads and margins of safety for all of the metallic and non-metallic components of the parachute system.

4.25.1.1 De-Rating of the Ultimate Factor of Safety for Textile Components

a) The structural analysis report provided per section 6.0 shall contain all de-rating factors applied to the ultimate factors of safety for the textile components and the justification for these de-rating factors including supporting test data.

b) Inspection of this report shall verify that the de-rating factors used in the design and analysis of the textile components meet the requirements of paragraph 3.25.1(b).

4.26 WIRE ROPE VERIFICATION REQUIREMENTS

Verification of wire ropes shall be by analysis and test.

a) When used as part of a spacecraft structural system, all wire rope shall be proof tested to a minimum of 2.0 times limit load.

b) The stress analysis report provided per section 6.0 shall contain a margin of safety summary table showing the factor(s) of safety used in analyzing any wire rope components.

c) Inspection of the stress analysis report shall verify that the ultimate factor of safety used in the design and analysis of wire rope components meet the requirements of section 3.10.1.

4.27 FLUTTER VERIFICATION

Flutter requirements shall be verified by analysis, test, or both.

4.27.1 Classical Flutter Verification

a) The flutter evaluation shall account for all pertinent aerodynamic, elastic, inertial and damping parameters and coupling mechanisms (e.g., mechanical, elastic and aerodynamic) as well as the effects of control-system characteristics and mechanical play, misalignments, launch-vehicle/spacecraft interface stiffness and degrees of freedom of the cryogenic tank-support structure.

b) If staging can occur in the atmosphere, the changes in vibration-mode characteristics and in the characteristics of the newly-activated control surfaces should be accounted for as well as the location of any lifting control surfaces.

4.27.1.1 Wind Tunnel Testing

If analytical methods are insufficient to satisfy paragraph 4.27.1, or when analysis indicates that instability may occur within 1.32 times the dynamic pressure (1.15 times the velocity), wind tunnel tests shall be conducted to demonstrate that the vehicle is free of classical flutter as specified in paragraph 3.27.1.

a) The test specimens shall be either dynamically-similar models or full-scale elements of the vehicle, which must be tested in relevant environments.

b) It shall also be demonstrated by influence-coefficient, structural stiffness, and/or vibration tests of full-size vehicles in the flight configuration that the scale models adequately simulate the dynamic characteristics of the vehicle.

c) Dynamic characteristics of the scale models shall also reflect the variation in modulus of elasticity with the anticipated service temperatures.

4.27.2 Stall Flutter verification

Stall flutter requirements shall be verified by analysis, which shall determine that the vehicle aeroelastic characteristics prohibit limit-cycle amplitude responses that could induce adverse loads on the structure. The verification shall include parametric analysis of vehicle stall flutter characteristics.

The analysis shall consider:

1) Separated-flow characteristics under all anticipated conditions of angle of attack and velocity;

2) Stiffness, inertia and damping characteristics of the aerodynamic surfaces; and

3) All significant degrees of freedom.

4.27.2.1 Wind Tunnel Testing

If analytical methods are insufficient to meet 4.27.2, or when analysis indicates marginal stability, wind tunnel tests shall be conducted per paragraph 4.27.1.1 to ensure compliance with 3.27.2.

4.27.3 Panel Flutter Verification

Verification of panel flutter shall be by test of selected panels with the lowest panel flutter margin.

a) If test data do not already exist for selected panels with the lowest flutter margin of similar structural configuration, edge support conditions and aerodynamic parameters, wind tunnel tests shall be conducted on dynamically-scaled models or full-scale components to demonstrate that external panels are free of panel flutter under the conditions defined in paragraph 3.27.3.

b) Thermally-induced loads, mechanically applied loads and pressure differentials across the panels shall be simulated in the tests.

4.27.4 Control Surface Buzz Evaluation through Testing

Wind-tunnel testing shall be conducted per paragraph 4.27.1.1 to demonstrate that the vehicle is free of control surface buzz under the conditions cited in paragraph 3.27.4.

4.27.4.1 Test Parameters

a) The test specimens shall be either dynamically-similar models or full-scale components.

b) Mach number shall be simulated in these tests and Reynolds number shall be as high as is achievable based on the model and test facility.

4.27.4.2 Flight Test

At least one flight test vehicle shall be instrumented to detect control surface buzz in flight test regions of greatest dynamic pressure. For recommended practices, refer to NASA SP-8003.

4.28 AEROELASTICITY VERIFICATION

Aeroelasticity requirements shall be verified by analysis, test or both.

4.28.1 Static Aeroelasticity Verification

4.28.1.1 Divergence Verification

When analysis is used to verify this requirement, the analysis shall include, as appropriate, such factors as static and transient thermal effects on distortion and stiffness, load magnitudes and distributions for all critical loading conditions, stiffness characteristics of the control-surface actuator system, system tolerances, misalignments and mechanical play.

4.28.1.1.1 Wind Tunnel Testing

a) If analytical methods are insufficient, wind tunnel tests shall be conducted per paragraph 4.27.1.1 to demonstrate that the vehicle is free of divergence under the conditions cited in paragraph 3.28.1.1.

b) For recommended practices, refer to NASA-SP-8003, FAA-FAR Part 25, AFSC DH 3-2 (DN 4C7) and MIL-A-008870 (USAF).

4.28.1.2 Verification of Aeroelastic Effects on Control Surfaces

When analysis is used to verify this requirement, the analysis shall include, as appropriate, such factors as static and transient thermal effects on distortion and stiffness, load magnitudes and distributions for all critical loading conditions, stiffness characteristics of the control-surface actuator system, system tolerances, misalignments and mechanical play.

4.28.1.2.1 Wind Tunnel Testing

a) If analytical methods are insufficient, wind tunnel tests shall be conducted per paragraph 4.27.1.1 to demonstrate that the vehicle is not subject to detrimental aeroelastic effects on control surface authority under the conditions cited in paragraph 3.28.1.2.

b) For recommended practices, refer to FAA-FAR Part 25 and MIL-A-008870(USAF).

4.28.2 Dynamic Aeroelasticity

4.28.2.1 Dynamic Aeroelastic Instability Evaluation by Analysis

The dynamic aeroelastic instability evaluation shall be performed by analysis and/or test.

The analysis shall account for:

1. Configuration effects, such as center-of-gravity offset leading to a coupled response;

2. Unsymmetrical stiffness distribution;
3. Variation in characteristics of the release-restraint device on the vehicle launch pad;
4. Variation in the thrust loads and unsymmetrical thrust effects resulting from engine sequencing and non-uniformity in combustion (including applicable engine-out conditions);
5. Unsymmetrical aerodynamic effects;
6. Changes in stiffness due to structural temperature;
7. Internal stress redistribution with increasing load level;
8. Effects of clearances and mechanical play;
9. Effects of non-linear aerodynamics such as moving shock waves.

4.28.2.2 Dynamic Aeroelastic Instability Evaluation by Test

When tests are conducted as a supplement to analysis to verify freedom from undesirable axial-lateral coupling, the following verification requirements are applicable:

a) The test specimens shall be either dynamically-similar models or full-scale components.

b) If dynamically-similar models are used, the adequacy of structural simulation shall be verified by influence-coefficient, structural-stiffness and/or vibration testing.

4.28.3 Vortex Shedding Verification

Verification of the flight vehicle structure's response to ground winds and gusts during pre-launch and launch shall be by analysis. If analysis is insufficient, supplemental testing shall be required.

4.28.3.1 Vortex Shedding Evaluation by Analysis

The analysis required to show that instabilities and excessive dynamic response due to vortex shedding produced by ground winds and gusts are precluded in Constellation Program flight vehicle structures shall account for, as a minimum:

1. The full range of specified ground wind and gust conditions;
2. The profile shape of the vehicle;
3. Vehicle mass, stiffness, propellant loading and tank-pressurization conditions;
4. Vehicle protuberances and surface roughness;

5. The characteristics of the release-restraint device on the vehicle launch pad;
6. Any changes in stiffness due to structural temperature;
7. The effects of clearances and mechanical play;
8. The proximity and shape of umbilical masts, gantries and other large structures;
9. Tank venting system characteristics, including valve tolerances and settings for design ullage and vent pressure;
10. Effects of any structural tie-offs or dampers used between the vehicle and launch-support structure to assist the vehicle in withstanding wind loads;
11. Proximity of unsteady vorticial frequencies to structural natural frequencies.

Refer to NASA SP-8008 for recommended practices.

4.28.3.1.1 Vortex Shedding Load Combination Criteria

The wind and gust loads as well as the other transient and quasi-static loads (including gravity effects, and any vehicle attachment loads due to the release-restraint devices, structural tie-offs or dampers) shall be combined with the periodic vortex shedding loads calculated from the peak-wind profile to obtain the resultant elastic-vehicle static and dynamic loads.

4.28.3.2 Vortex Shedding Evaluation by Test

When tests are conducted as a supplement to analysis to verify freedom from instabilities and excessive dynamic response due to vortex shedding produced by ground winds and gusts, the test specimens and test methods shall meet the requirements of the next two paragraphs. Refer to NASA SP-8008 for recommended practices.

4.28.3.2.1 Dynamically-Similar Wind-Tunnel Models

When wind tunnel tests are conducted as a supplement to analysis, these tests shall meet the following:

a) Dynamically-similar wind-tunnel models of the vehicle and its restraint on the launch pad shall be used.

b) The vehicle model shall incorporate all protuberances.

c) The influence of adjacent towers and launch equipment shall be simulated.

d) Tests shall be conducted in all critical configurations for all orientations with respect to the wind at both subcritical and supercritical Reynolds numbers.

4.28.3.2.2 Full-Scale Tests

When full-scale tests are conducted as a supplement to analysis, these tests shall meet the following:

a) Full-scale tests including the flight vehicle, or a representative test article, shall be restrained at the launch pad and include the surrounding structure.

b) These tests shall provide measurements of vehicle dynamic response such as bending moments and accelerations as well as simultaneous measurements of the frequency and damping of the critical vibration modes of the vehicle on its launch pad in all necessary configurations.

4.28.4 Buffeting Verification

Verification of the flight vehicle structural response to buffet shall be by analysis. If analysis is insufficient, supplemental testing shall be required and shall account for scaling effects.

4.28.4.1 Buffeting Analysis

When analysis is used to verify this requirement, the analysis shall consider low frequency buffeting effects in areas where separated flow or rocket engine exhaust plume produce a bending response of the mated or unmated vehicle configuration. High-frequency buffet loads resulting from local impingement of a turbulent flow shall be accounted for in the analysis.

4.28.4.2 Buffeting Analysis Considerations

The analysis of buffeting effects shall consider both local and overall vehicle response and stability and shall account for such factors as aerodynamic interferences vehicle cross-section shape and area changes, protuberances and structural flexibility.

4.28.4.3 Buffeting Evaluation by Test

When tests are conducted as a supplement to analysis to verify freedom from instabilities and excessive dynamic response due to buffeting, the test specimens and test methods shall meet the requirements of the next paragraph. Refer to NASA SP-8001 for recommended practices.

4.28.4.4 Dynamically-Similar Wind-Tunnel Models for Buffeting

When wind tunnel tests are conducted as a supplement to analysis, these tests shall meet the following:

a) Dynamically-similar wind tunnel models of the vehicle shall be used to account for scaling effects.

b) The vehicle model shall incorporate all protuberances.

c) Tests shall be conducted in all critical configurations for all orientations with respect to the wind at both the appropriate Mach numbers and Reynolds numbers.

5.0 STRUCTURAL TEST REQUIREMENTS

a) A test plan showing the proposed loading conditions, structural configuration to be tested, and method of test, including load application and instrumentation, shall be prepared and submitted to NASA per paragraph 1.5 for approval.

b) All static testing shall provide data to develop a test-verified strength math model. Requirements for successful strength correlation are listed in section 4.9.2.

5.1 VERIFICATION TEST OPTIONS

5.1.1 Static Test to Ultimate Loads

a) A designated structural test article shall be static tested to ultimate loads for the critical load conditions to demonstrate the minimum required factors of safety per Table 3.10-1.

b) Sufficient instrumentation shall be utilized to identify (monitor) high strain areas and verify that the internal loads distribution, strains and displacements are consistent with the structural math models.

5.1.2 Protoflight Static Test

a) Flight structure shall be static tested to 1.2 times the design limit loads.

b) Sufficient instrumentation shall be utilized to identify (monitor) high strain areas and verify the internal loads distribution, strains and displacements are consistent with the structural math model.

c) After verification of the analytical static math model per section 4.9.2, ultimate load capability can then be verified by a formal stress analysis.

d) The minimum yield factor of safety shall be 1.25 for the structure to be verified by this option.

e) Use of this option requires prior approval of NASA per paragraph 1.5.

5.1.3 Element and Critical Component Static Test

The hardware developer shall demonstrate prior experience in successful structural design and analysis, math modeling, and structural testing of previous spacecraft. This option requires prior written approval by NASA per paragraph 1.5.

5.1.3.1 Element Tests and Model Verification

a) Flight structure shall be proof tested to 1.1 times the design limit loads.

b) Sufficient instrumentation shall be utilized to identify (monitor) high strain areas and verify the internal loads distribution, strains and displacements are consistent with the structural math model.

c) After verification of the analytical static math model per section 4.9.2, ultimate load capability can then be verified by a formal stress analysis

5.1.3.2 Complementary Component Testing to Ultimate Load

a) In addition to the 1.1 times limit load proof test, several critical structural elements and/or components shall be tested to ultimate load to verify their ultimate strength capability. These components shall be identified prior to initiating the test program and shall be approved by NASA per paragraph 1.5.

b) These critical structural elements and/or components verification tests may be conducted on dedicated test articles having the same configuration, materials and workmanship as the flight article.

5.2 VERIFICATION TESTS REQUIREMENTS

5.2.1 General Requirements

All test plans and requirements shall be coordinated with and approved by NASA per paragraph 1.5.

5.2.1.1 Static Strength Tests

a) Test loads shall duplicate or envelop all flight loads and include pressure and temperature effects as specified in the SVP.

b) When a separate verification structure (dedicated test article) is used, the tests shall be accomplished at the limit and ultimate levels specified by the required factors of safety.

c) Testing to an ultimate FS is for structural design verification only and not for attached systems.

5.2.1.2 Dynamic Strength Tests

Sinusoidal dynamic tests may be used when warranted by load conditions, test article size, and boundary conditions. Other forms of dynamic testing may be warranted, e.g., impact testing.

5.2.1.3 Proof Test for Flaw Screening

When proof tests are used for flaw screening, the proof test factor shall be the larger of the values determined by the fracture mechanics analysis derived proof test requirements to meet service life per paragraph 1.2 or those specified in Table 3.10-1.

5.2.2 Test Boundary Conditions

The stiffness and boundary conditions of the interfacing flight structure through which the loads and reactions are applied shall be simulated for statically indeterminate structure.

5.2.3 Pressurized Hardware Verification Tests

5.2.3.1 Acceptance Proof Tests for Pressurized Hardware

a) Every item of pressurized hardware shall be proof pressure tested to the appropriate pressure as defined in Table 3.10-1 to verify that the hardware has sufficient structural integrity to sustain the subsequent service loads, pressure, temperatures, and environments.

b) This test shall be conducted as an acceptance test of each production unit including the qualification article.

5.2.3.1.1 Proof Pressure Test Description

a) The unit shall be subjected to a minimum of one cycle of proof pressure.

b) A proof pressure cycle shall consist of raising the internal pressure (hydrostatically or pneumatically, as appropriate) to the proof pressure, maintaining it for five minutes and then decreasing the pressure to ambient. When the proof factor is increased above the requirements in Table 3.10-1 to meet fracture control requirements, the test duration may be decreased with approval of the System technical authority.

c) Valves shall be tested in both the open and the closed positions with the proof pressure applied for a minimum of one cycle to the inlet port for five minutes in each configuration. Following the five-minute pressurization period, the inlet pressure shall be reduced to ambient conditions.

5.2.3.1.2 Proof Pressure Test Pass/Fail Criteria

a) Accept/reject criteria shall be formulated prior to acceptance proof test.

b) When sufficient data do not exist to establish these criteria, a development test program shall be conducted to generate the required data.

c) Evidence of leakage in excess of specification requirements, a permanent set or distortion that exceeds a drawing tolerance, a permanent change in volume or linear dimensions exceeding a specified allowable or failure of any kind shall constitute failure to pass the test.

5.2.3.1.3 Special NDE Requirements for Habitable Modules

a) One hundred percent non-destructive inspection of all welded joints in the pressure shells of habitable modules shall be performed before and after the module's proof pressure test to demonstrate structural integrity and to provide data for the structural life analysis.

b) The NDE levels for these inspections shall be specified on the engineering drawings for the habitable module pressure shell.

5.2.3.2 Qualification Pressure Test Requirements for Pressurized Hardware

a) Qualification testing shall demonstrate that failures do not occur at the design burst (ultimate) pressure.

b) Qualification pressure testing shall not be imposed on flight units.

5.2.3.2.1 Hardware Requirements for Pressurized Hardware Qualification Testing

a) Qualification testing on pressurized hardware shall be conducted on flight-quality hardware to demonstrate structural adequacy of the design.

b) The test fixtures, support structures, and methods of environmental application shall not induce erroneous test conditions.

c) The sequences, combinations, levels and duration of loads, pressure, and environments shall demonstrate that design requirements have been met.

5.2.3.2.2 Pressure Cycle Testing for Qualification of Pressure Vessels and Pressurized Structures

a) Pressure vessels and pressurized structures shall undergo a pressure cycle test for qualification.

   These requirements do not apply to habitable modules or their doors or hatches.

b) Pressure cycle testing shall be performed for qualification only and shall not be imposed on actual flight units.

c) Requirements for application of external loads in combination with internal pressures during testing shall be evaluated based on the relative magnitude and on the destabilizing effect of stresses due to the external load.

d) If limit combined tensile stresses are enveloped by the test pressure stress, the application of external load is not required.

5.2.3.2.3 Load Application for Pressure Cycle Testing

a) The pressure cycle test pressures, and any requirement for the application of external load during the test, shall be established on a case-by-case basis considering the unit's life cycle requirements including acceptance testing, ground processing, and mission requirements.

b) The number of pressure cycles shall be sufficient to demonstrate four times the life required.

c) The applicable test plan shall fully and clearly establish the basis for the test conditions per the above criteria.

5.2.3.2.4 Load Application for Qualification Burst Testing

a) The qualification test article shall be pressurized (pneumatically or hydrostatically, as applicable and safe) to the design burst pressure specified in Table 3.10-1, while simultaneously applying the ultimate external loads, if appropriate.

b) The internal pressure shall be applied at a sufficiently slow rate such that dynamic loads are not imposed.

c) The design burst pressure shall be maintained for a period of time sufficient to verify that the hardware does not fail when subjected to design burst pressure.

d) Valves shall be tested in both the open and the closed positions with the design burst pressure applied to the inlet port while simultaneously applying the ultimate external load(s), if appropriate.

5.2.3.3 Environmental Conditions for Verification Testing of Pressurized Hardware

a) Environmental conditions during the test shall be consistent with the environmental conditions of service for environments known to adversely affect material strength or fracture toughness.

   1. As an alternative, tests may be conducted at ambient conditions if the test pressures and/or external loads are suitably adjusted to account for environmental effects on material strength and fracture toughness.

2. Criteria necessary to establish that adjustments are suitable include a documented correlation between the proposed adjusted test condition and design or development data that establishes the relationship between the (usually accelerated) test condition and the actual operating condition.

b) Proof-test fluids shall be compatible with the materials in the pressurized hardware.

If such compatibility data is not available, testing shall be conducted to demonstrate that the proposed test fluid does not deteriorate the test article.

c) The applicable test plan shall fully and clearly establish the basis for the environmental conditions of the test in relation to the unit's life cycle environments.

5.2.4 Rotating Machinery Verification Tests

Verification testing shall include proof spin test factor, FS_{spin}, of at least 1.1 and an ultimate spin test factor of at least 1.2 per equation 5.2-1.

Qualification and proof tests shall be conducted in the operational environment. If testing in the operational environment is not feasible, tests can be performed in a non-operational environment if an environment correction factor (ECF) is applied. An ECF is a factor to be multiplied by the test load to compensate for the environmental effect on the strength (E, Fty, Ftu, fracture toughness, etc.) capability at test conditions versus the operating condition.

$$Test\ Speed = \sqrt{FS_{spin} \cdot ECF \cdot (Maximum\ design\ speed)^2} \geq \sqrt{1.05 \cdot (Maximum\ design\ speed)^2} \qquad (5.2\text{-}1)$$

5.3 REPORTS

5.3.1 Qualification Test Reports

a) Qualification tests shall be documented.

b) The documentation shall include a summary of the objectives of the test, a description of the test article configuration including locations of instrumentation, a description of the test boundary conditions, a summary of the applied loads and their method of application, a summary of projected internal loads, stresses and forces compared against the actual internal loads, stresses and forces developed during test and a summary of test data which is applicable to the structural verification.

5.3.2 Engineering Analysis Reports

An engineering analysis report shall be prepared for each structural qualification test. The report shall compare the test results to the analysis of the test configuration.

6.0 STRESS ANALYSIS REQUIREMENTS

Structural margins of safety for limit and ultimate loads shall be evaluated in order to ensure that adequate margin exists for the combination of mechanical, pressure, and thermal loads.

6.1 STRESS/LOAD COMBINATION RESTRICTIONS

Guidelines for combining mechanical loads may be found in NASA-TM-X-73305. The following restrictions shall be applied for load combinations.

6.1.1 Combining with Pressure Stress/Load

a) In circumstances where pressure loads have a relieving or stabilizing effect on structural load capability, the minimum value of such relieving loads shall be used.

b) The pressure loads shall not be multiplied by the FS in calculating the design limit or ultimate load if they are relieving or stabilizing to the structure.

c) Factors of safety for combined load conditions are defined in paragraph 3.10.

   For example, the ultimate compressive load in pressurized vehicle tankage shall be calculated as follows:

   Ultimate Load = (Ultimate FS X Mechanical Load) - (Min Pressure Load)

6.1.2 Combining Low Frequency And Random Loads For Components And Attachments

Low frequency loads and random vibro-acoustic loads shall be combined according to Table 6.1-1, Load Combination Criteria for Components, to determine the loads for components of Constellation Program systems. Time-consistent loads may be considered in the final loads cycle with NASA approval per paragraph 1.5.

With Level II Loads Panel approval, systems may tailor the method for determining component loads and shall define that method in the SRD. Further discussion of system-level loads shall occur at the technical authority designated in the SRD. Constellation Program integrated loads shall be reviewed and approved at the Level II Loads Panel.

Table 6.1-1 Load Combination Criteria for Components

Axis	Steady State Load (Limit)	Low Frequency Transient Load[1,2]	Random Load[3]
V_i	QS_i	+/- Si	+/- R_i
Combined Loads Load in Each Axis Acting Simultaneously			
Load Set	V_1 Axis	V_2 Axis	V_3 Axis
1	$QS_1 +/-(S_1^2 + R_1^2)^{1/2}$	$QS_2+/-(S_2^2 + (R_2/3)^2)^{1/2}$	$QS_3+/-(S_3^2 + (R_3/3)^2)^{1/2}$
2	$QS_1 +/-(S_1^2 + (R_1/3)^2)^{1/2}$	$QS_2+/-(S_2^2 + R_2^2)^{1/2}$	$QS_3+/-(S_3^2 + (R_3/3)^2)^{1/2}$
3	$QS_1 +/-(S_1^2 + (R_1/3)^2)^{1/2}$	$QS_2+/-(S_2^2 + (R_2/3)^2)^{1/2}$	$QS_3+/-(S_3^2 + R_3^2)^{1/2}$

[1]quasi-static portion removed
[2]based on three-sigma predictions and case-consistent, when available
[3]three-sigma Gaussian random load

6.2 STRUCTURAL ANALYSIS DOCUMENTATION

The responsible design organizations shall provide stress analysis documentation of all structure to assure compliance with strength and deformation requirements.

6.2.1 Stress Analysis Format

The stress analysis reports shall be prepared in accordance with standard aerospace industry practices for flight hardware. Guidelines for stress analysis reports are documented in JSC 19652, Instructions for the Preparation of Stress Analysis Reports.

6.2.2 Solution Description and Verification

If the results from other than closed form solutions, e.g., computer models, are presented in a stress analysis, both the logic and sufficient checks shall be present to assure that the data presented is a solution to the configuration and condition being analyzed.

6.2.3 Stress Analysis Maturity and Deliveries

a) Stress analysis reports shall be submitted to NASA in support of the following four design reviews: Preliminary Design Review (PDR); Critical Design Review (CDR); Design Certification Review (DCR); and Flight Readiness Review (FRR), as delineated in the following paragraphs.

b) These analyses shall be current with respect to loads and the design at the time of the review.

6.2.3.1 Stress Analysis for Preliminary Design Review

The PDR stress analysis shall be sufficiently detailed to assure the structural integrity of all major structure elements and the credibility of weight calculations. Additionally, a preliminary structural life assessment, including a preliminary fatigue analysis, shall be submitted for PDR.

6.2.3.2 Stress Analysis for Critical Design Review

a) This analysis shall fully substantiate the structural integrity of each detailed part and provide the basis for stress signatures required on all drawings.

b) Each page of the stress analysis report shall be checked and approved by a person or persons other than the primary analyst.

c) Life requirements shall be addressed in this analysis.

6.2.3.3 Interim Design Reviews

Current stress analyses shall be available to support interim reviews other than those specified above.

6.2.3.4 Stress Analysis for Design Certification Review (DCR)

This analysis shall include changes or additions to the formal CDR stress analysis data package and shall fully substantiate the structural integrity of each detailed part including structural verification tests, life verification, and detailed evaluation of the "as-built" hardware.

6.2.3.5 Stress Analysis for Flight Readiness Review

These data shall include only revisions to update the stress analysis reports for the flight design configuration with all significant changes from the DCR.

6.2.4 Fatigue and Fracture Analysis Deliveries

Fatigue and fracture analyses shall be submitted according to the stress analysis reporting schedule in section 6.2.3, or according to a schedule in an approved fracture control plan.

7.0 QUALITY ASSURANCE, STRUCTURAL INSPECTION AND MAINTENANCE REQUIREMENTS

The type, extent, and frequency of structural inspections, and the special instrumentation required to maintain safety shall be documented in an inspection plan. The plan shall be approved by NASA.

7.1 STANDARD REPAIR MANUAL

The hardware provider shall develop a Standard Repair Manual (SRM).

The SRM shall include the following:

a) A diagrammatic break-down of the hardware’s structural components;

b) For complicated vehicles or systems this break-down shall be divided into zones consistent with inspection and maintenance activities;

c) Criteria for accepting defects in key structural components that are susceptible to damage during manufacturing and processing;

d) Generic repair procedures categorized by the nature of the defect in specific types of structure.

8.0 GLOSSARY

The following definitions and terms shall be used for design and analysis of the stage or vehicle to establish uniform structural nomenclature in all documentation:

ACCEPTANCE TESTS

Tests performed on flight hardware and software to confirm equipment performs as qualified and is generally free of latent manufacturing, material, or workmanship defects for delivery of products. For hardware, acceptance testing is typically performed at operating and non-operating performance and environment limits without intruding into qualification margins. For software, acceptance testing ensures the software will load and execute on each serialized hardware platform.

A-BASIS MATERIAL PROPERTIES

The lower of either a statistically calculated number, or the specification minimum (see S-basis). The statistically calculated number indicates that at least 99 percent of the population of values is expected to equal or exceed the A-basis mechanical design property, with a confidence of 95 percent.

ALLOWABLE LOAD OR STRESS

The load or stress which is consistent with the limits imposed by the structural criteria being addressed when considering minimum material dimensions and material properties. An allowable load based on yield criteria is the maximum load at which structural yielding will not occur. An allowable load based on ultimate criteria is the maximum load at which structural failure will not occur. If configuration-specific tests are used to determine allowable load, test data must be corrected to minimum dimensions and minimum material allowable properties.

B-BASIS MATERIAL PROPERTIES

At least 90 percent of the population of values is expected to equal or exceed the B-basis mechanical property allowable, with a confidence of 95 percent.

BURST SPEED, ROTATING MACHINERY

The burst speed for rotating machinery is the calculated speed at which the rotor disk average tangential stress equals the material ultimate tensile strength of the rotor disk multiplied by a material utilization factor of 0.7.

CATASTROPHIC HAZARD

The presence of a potential risk situation caused by an unsafe condition that can result in a disabling or fatal personnel injury, or loss of one of the following: launch or servicing vehicle, ISS, or major ground facility.

COMPONENT

A hardware item that is considered as a single structural entity. The terms “component” and “part” are interchangeable in this document.

CONDITION

A phenomenon, event, time interval, or combination thereof to which the space vehicle is exposed. (See Design Condition.)

CREDIBLE FAILURE

A failure resulting from a Program-accepted load or design condition.

CREDIBLE LOAD, DESIGN CONDITION

A Program-accepted load or design condition.

CREDIBLE SINGLE BARRIER FAILURE

Potential leaks within a component that permits fluid to directly contact the materials behind the barrier or expose secondary compartments to system pressure conditions.

CREEP

A time-dependent deformation under load and thermal environments which results in cumulative permanent deformation.

CRITICAL FLAW SIZE

The flaw size which, for a given applied stress, causes unstable flaw propagation.

CRITICAL

The extreme value of a load or stress; the combination of loads causing the maximum stress in a structural member; or the most severe environmental condition imposed on a structure during its service life. The design of the structure is based on an appropriate combination of such critical loads, stresses, and conditions.

CRITICAL SEALS

See Seals, Critical

DERATING FACTORS

The load and loss factors applied to the factor of safety for each textile load bearing component to account for the strength degradation of textiles due to mechanical, environmental and material conditions.

DESIGN CONDITION

A condition important in structural design and which may involve a specific point in time or integrated effects over a period of time in terms of physical units such as pressure, temperature, load, acceleration, attitude, rate, flux, etc. (See Condition.)

DESIGN ORGANIZATION

The organization which has the responsibility for the detailed design, analysis, and verification of the flight hardware being discussed. Normally the design organization will be a contractor organization.

DESIGN SPEED, ROTATING MACHINERY

The nominal fluid characteristics for rotating machinery are designed based upon this speed.

DETERMINISTIC

Denotes that values used in design are discrete and not random. Deterministic values are determined on the basis of available information and experience. (See Probabilistic.)

DETRIMENTAL DEFORMATION

Structural deformation, deflection, or displacement which: (1) causes unintentional contact, misalignment, or divergence between adjacent components; (2) causes significant internal load redistribution in a structure; (3) causes a component to exceed the dynamic space envelop established for that component; (4) reduces the strength or rated life of the structure below specified levels; (5) degrades the effectiveness of thermal protection coatings or shields; (6) jeopardizes the proper functioning of equipment; (7) endangers personnel; (8) degrades the aerodynamic or functional characteristics of the vehicle; 9) reduces confidence below acceptable levels in the ability to ensure flight-worthiness by use of established analytical or test techniques; or (10) induces leakage above specified rates.

DEVELOPMENT TEST

Any test that provides data needed to reduce risk, to define or mature requirements, to design hardware or software, to define manufacturing processes, to define qualification or acceptance test procedures, or to investigate anomalies discovered during test or operations.

DISCONTINUITY AREA

A local region of a composite or non-metallic structure consisting of built-up plies, chopped fiber or reinforced regions around fittings, joints or interfaces where the stress state and load distribution within the region may be difficult to characterize. A region is considered a discontinuity area until uniform section properties in the structure can be considered in the structural analysis. Bonded joints are considered discontinuities.

ELEMENT

Constellation Program physical entities that have functional capabilities allocated to them necessary to satisfy System-level mission objectives. Elements can perform all allocated functions within a mission phase, or through mated operations with other Constellation Program elements or systems (e.g. Crew Module (CM), Core Stage).

ENVIRONMENTAL CORRECTION FACTOR (ECF)

An adjustment factor used to account for differences in the environment (thermal and chemical) in which the part is used and the environment in which it is tested.

$$ECF = \frac{\text{Strength capability at test condition}}{\text{Strength capability at operating condition}}$$

FAIL-SAFE

A structural design criterion in which it must be shown that the structure remaining, after failure of any single structural member, can withstand the resulting redistributed internal limit loads without failure. The ability to sustain a failure and retain the capability to safely terminate or control the operation.

FAILURE

A rupture, collapse, or seizure; an excessive wear; or any other phenomenon resulting in the inability of a structure to sustain required loads, pressures, and environments.

FAILURE, CREDIBLE

A failure of a component, device, or structure which is from an accepted or credible design condition.

FASTENER, STRUCTURAL

See Structural Fastener.

FATIGUE

The cumulative irreversible damage in materials and structures incurred by the cyclic application of loads and environments. Fatigue is usually considered as the number of cycles to crack initiation or to failure.

FATIGUE, STATIC

The phenomena where flaws grow as a function of sustained stress, time, flaw size, and environment.

FITTING

A part or terminal used to join one structural member to another.

FLAWS OR CRACK-LIKE DEFECTS

Defects which behave like cracks that may be initiated during material production, fabrication, or testing or may be developed during the service life of a component.

FLIGHT VEHICLE

A vehicle, which is generally composed of multiple elements, used to transport persons or things to a location outside of the Earth's atmosphere.

FRACTURE

Fracture is used herein in a broad sense to encompass the development, accumulation and/or growth of damage in various forms such as cracks, flaws, notches, delaminations, disbonds, cuts, voids, etc. whose growth could lead to component failure.

FRACTURE CONTROL PLAN

The plan which specifies fracture control activities to be imposed on the design, analysis, testing, change control, and documentation of components. The intent of this document is to establish procedures required to prevent catastrophic damage associated with cracks or crack-like flaws from occurring during the service life of these components.

FRACTURE CONTROL

The rigorous application of those branches of engineering, assurance management, manufacturing, and operations technology dealing with the understanding and prevention of flaw propagation leading to catastrophic failure.

FRACTURE CRITICAL COMPONENT (OR PART)

A classification that identifies a part whose individual failure is a catastrophic hazard, and which requires damage tolerant analysis or other fracture control assessments to be shown acceptable for flight.

FRACTURE MECHANICS

An engineering discipline which describes the behavior of cracks or crack-like flaws in materials under stress.

GROUND OPERATIONS

For requirements purposes Ground Operations is the collection of ground activities performed at the launch, landing and retrieval sites including receiving, ground processing, integration, integrated and interface testing, launch operations, recovery, de-integration, refurbishment, disposal, pad abort, and search & rescue operations. In a broader context, Ground Operations also describes the organizations and processes required to perform these activities.

GROUND PROCESSING

The operations performed to prepare flight systems, elements and cargo for integration. Ground processing includes the assembly, element to element integration, functional verification, commodity servicing, ordnance installation, and pre-integration closeouts for flight systems. Ground Processing also includes the transportation of flight systems for integration.

GROUND SUPPORT EQUIPMENT (GSE)

Non-flight systems, equipment, or devices necessary to support such operations as transporting, receiving, handling, assembly, inspection, test, checkout, servicing, launch, and recovery of space systems, including spacecraft, launch vehicles, and payloads at launch, landing, or retrieval sites.

HABITABLE MODULE

A pressurized, life-supporting enclosure or module that is normally intended to support life without the need for spacesuits or special breathing apparatus. The enclosure may be one that is continuously inhabited, or one that is used for crew transference, or for crew accessible stowage so long as life support is a requirement for the design. Single mission or multi-mission module designs are included.

INDUCED ENVIRONMENT

Any form of matter or energy released, radiated or modified by one component or System that could impact or influence another component or System. Includes radiated and reflected thermal energy; vibrations, aerodynamic and shock loads; electromagnetic energy, Paschen discharge, arcing, glow discharge, spacecraft charging and V x B voltages; debris; particulate and molecular contamination, waste water dumps; and reflections, glows, and other optical contamination.

INITIAL FLAW OR CRACK SIZE

The maximum size of the flaw or crack, as determined by proof test or nondestructive inspection, which could exist in parts without failure in proof test or detection by inspection.

INTERFACE

The common boundary between components, assemblies, or systems of a space vehicle. An interface may be physical, functional, or procedural.

LOAD DE-RATING FACTORS

The type of de-rating factor that is used to addresses uncertainties in load magnitude and in the geometry of the load paths when analyzing textiles in a parachute system. Examples of these factors include dynamic load factor, line convergence factor and unsymmetrical suspension line load distribution.

LOAD, FLUCTUATING

An oscillating load in which the duration, direction, magnitude, frequency content, and phase are significant. Dynamic response of the structure may or may not be significant. Examples are loads caused by pogo-type instability, flutter, buffeting, aerodynamic noise, acoustic noise, and rotating equipment.

LOAD, IMPULSE

A suddenly applied pulse or step change in loading in which the duration, direction, magnitude, and rate of change in direction or magnitude are significant. Examples are loads produced by physical impact, vehicular pyrotechnics, and external explosions.

LOAD, LIMIT

The maximum load expected on the structure during its design service life including ground handling, transport to and from orbit including abort conditions, and on-orbit operations.

LOAD, QUASI-STATIC

A time-varying load in which the duration, direction, and magnitude are significant, but the rate of change in direction or magnitude and the dynamic response of the structure are not significant.

LOAD SPECTRUM

A representative distribution with respect to time of the cumulative static and dynamic loadings anticipated for a structural component or assembly under all expected operating environments.

LOAD, STEADY

A load of constant magnitude and direction with respect to the structure. Examples are loads caused by joint preloads, clamping, and constant thrust.

LOADS, TIME-CONSISTENT

A set of time-consistent loads is one in which all of the load events being assessed occur at the same time during a vehicle’s mission or life.

LOSS DE-RATING FACTOR

The type of de-rating factor that is used to addresses the mechanical and environmental conditions which degrade the strength of the parachute textile material. Examples of these factors include joint efficiency loss, abrasion loss, re-use, cyclic, environmental effects (e.g. temperature, water, chemicals, aging and sunlight), humidity, and storage in the space environment.

MARGIN OF SAFETY (MS)

The parameter utilized by the structural discipline to express structural capability in terms of structural requirements which include factor of safety. Margins of safety are expressed for both yield and ultimate criteria. A detailed discussion of Margins of Safety including combined stresses is presented in Sec. 1.5.3.5 of MIL-HDBK-5. The basic equation defining margin of safety for uniaxial stress (which does not apply for combined stresses) is:

$$MS = \frac{\text{allowable stress (yield or ultimate)}}{\text{FS (yield or ultimate)} \times \text{limit applied stress}} - 1$$

MATH MODEL, STRUCTURAL

The mathematical equations, boundary values, initial conditions, and modeling data needed to describe the conceptual model of a structure.

MAXIMUM DESIGN PRESSURE

The maximum design pressure (MDP) for a pressurized system is the highest pressure defined by the maximum relief pressure, maximum regulator pressure, maximum temperature and transient pressure excursions based on two credible system failures.

MAXIMUM DESIGN SPEED (MDS)

The highest possible operating speed based on a combination of credible failures; critical equipment must consider two credible failures. Certain liquid propulsion system engines will not meet this definition.

MAXIMUM EXPECTED OPERATING PRESSURE (MEOP)

The maximum pressure which the pressurized hardware is expected to experience during its service life, in association with its applicable operating environments.

MAXIMUM OPERATING SPEED, ROTATING MACHINERY

The Maximum Operating Speed for rotating machinery is equivalent to Design Speed multiplied by a factor of 1.1.

MISSION

A flight to a destination in space, intended to accomplish specific scientific and technical objectives. Mission phases include TBS.

NON-DESTRUCTIVE EVALUATION (NDE)

Inspection techniques which do not cause physical, mechanical, or chemical changes to the part being inspected or otherwise impair its adequacy for operational service. These inspection techniques are applied to materials and structures to verify required integrity and to detect flaws.

NON-SAFETY CRITICAL STRUCTURES

Structures which if they fail will not create a catastrophic hazard.

POGO

“POGO” is a potentially dangerous type of oscillation found in rocket engines. This oscillation results in variations of thrust from the engines, generally caused by variations in fuel flow rate, placing stress on the frame of the vehicle. The main cause of POGO is when a surge in engine pressure increases back pressure against the fuel coming into the engine, reducing engine pressure, causing more fuel to come in and increasing engine pressure again. If the cycle happens to match a resonant frequency of the rocket then dangerous oscillations can occur through positive feedback, which can in extreme cases tear the vehicle apart.

PRESSURE VESSEL

A container designed primarily for pressurized storage of gases or liquids and:
(1) Contains stored energy of 14,240 foot-pounds (19,307 joules) or greater based on adiabatic expansion of a perfect gas; or
(2) Contains a gas or liquid in excess of 15 psia (103.4 kPa) which will create a hazard if released; or
(3) Stores a gas which will experience a MDP greater than 100 psi (689.5 kPa).

PRESSURIZED STRUCTURE

A structure designed to carry vehicle loads in which pressure is a significant contributor to the design loads. Pressurized structures are typically large tanks or habitable structures that carry external flight loads as well as containing the internal fluids or gases.

PRESSURIZED SYSTEM

A system that consists of pressure vessels, pressurized structures, or both, and other pressure components such as lines, fittings, valves, and bellows that are exposed to and structurally designed largely to carry or store pressurized gases or liquids. Not included are electrical or other control devices required for system operation.

PRIMARY STRUCTURE

(See Structure, Primary.)

PRELOADED JOINT

A preloaded joint is a joint in which the preload is necessary to have adequate life due to cyclic loads, or to assure that no joint separation and resulting stiffness change occurs, or to assure that no joint separation occurs which would affect pressure seals.

PROBABILISTIC

Denotes that the values used in design are random, not discrete. Probabilistic values are chosen on the basis of statistical inference. (See Deterministic.)

PROOF LOAD OR PRESSURE

The product of the limit load or pressure and the proof factor.

PROOF TEST

A load or pressure in excess of limit load or maximum design pressure applied in order to verify the structural integrity of a part or to screen initial flaws in a part.

PROTOTYPE STRUCTURE

A separate flight-like structural test article used in a test program to verify structural integrity of the design. Prototype tests and qualification tests are synonymous.

PROTOFLIGHT STRUCTURE

Flight hardware utilized for ground qualification testing in lieu of a dedicated test article. The approach includes the use of reduced test levels and/or durations and post-test hardware refurbishment where required.

QUALIFICATION

Verification activities conducted to prove the design on the first article produced, has a predetermined margin above expected operating conditions, for instance by using elevated environmental conditions for hardware.

QUALIFICATION TEST

Formal test conducted with defined qualification margin as part of the certification program to qualify a design, manufacturing process, and acceptance testing program to produce equipment able to accomplish the full range of performance requirements in all predicted operating and non-operating service life environments.

RANDOM VIBRATION

The oscillating haphazard motion of a structure caused by acoustical and/or mechanical forcing functions.

ROTATING MACHINERY

Devices with spinning parts such as fans, centrifuges, motors, pumps, gyros and flywheels.

SAFETY CRITICAL

An event, system, subsystem or process, that if lost or degraded, would result in a critical or catastrophic hazard.

SAFETY FACTOR (FS)

A constant which has been defined for yield and ultimate design criteria which is multiplied by limit load to obtain the yield and ultimate design loads. FS has an historical basis and is necessary to assure no failures due to uncertainties which result from the design process, analysis, manufacturing process, and the loading environment.

S-BASIS MATERIAL PROPERTIES

The S-value is the minimum property value specified by the governing industry specification (as issued by standardization groups such as SAE Aerospace Materials Division, ASTM, etc.) or federal or military standards for the material. (See MIL-STD-970 for order of preference for specifications.) For certain products heat treated by the user (for example, steels hardened and tempered to a designated F_{tu}), the S value may reflect a specified quality-control requirement. Statistical assurance associated with this value is not known.

SEALS, CRITICAL

A critical seal is one through which leakage would constitute a catastrophic or critical failure. Seals through which atmosphere of any habitable volume may leak to the external environment are critical seals. Seals through which flow may intrude into the spacecraft during atmospheric entry are critical seals.

SEAM

A series of stitches that joins two or more pieces of fabric or material.

SECONDARY STRUCTURE

(See Structure, Secondary.)

SERVICE LIFE

The interval beginning with determination of initial crack size for analysis based on inspection or flaw screening proof test of a part through completion of its specified mission item starting at the completion of fabrication and continuing through all levels of acceptance testing, handling, transportation, storage, pre-launch processing, all phases of flight, recovery, rework or refurbishment, retest, and reuse as required or specified.

STATIC LOAD

A load of constant magnitude and direction with respect to the structure.

STIFFNESS

Structural resistance as a function of deflection or rotation under an applied force or torque.

STRENGTH, MATERIAL

The stress level that a material is capable of withstanding in a local structural configuration and expected operating environments. Units are expressed in force per unit area using the original dimensions of the unloaded section.

STRENGTH, ULTIMATE

Corresponds to the maximum load or stress that a structure or material can withstand without incurring rupture or collapse.

STRENGTH, YIELD

Corresponds to the maximum load or stress that a structure or material can withstand without incurring permanent deformation.

STRESS, ALLOWABLE

The maximum stress that can be permitted in a material for a given design condition to prevent rupture/collapse for ultimate conditions or detrimental deformation for yield conditions.

STRESS, APPLIED

The stress induced by applied loads and thermal gradients.

STRESS, LIMIT

The maximum stress expected in the structure during its design service life including ground handling, transport to and from orbit including abort conditions, and on-orbit operations.

STRESS, RESIDUAL

Stress that remains in a structure due to processing, fabrication, or non-uniform yielding.

STRESS, THERMAL

The stress from temperature gradients and differential thermal expansion between structural components, assemblies, or systems.

STRUCTURAL ADEQUACY OR INTEGRITY

A structure that complies with correctly specified design requirements.

STRUCTURAL DESIGN TEMPERATURES

Temperature distributions of the structure when it is subjected to critical combinations of loads, pressures, and temperatures.

STRUCTURAL FASTENER

A fastener used in either the primary or secondary load path of a structure.

STRUCTURAL SEAL

A structural seal is one which is mounted in a static structural interface and prevents air flow from a high-pressure area to a lower pressure area.

STRUCTURE

All components and assemblies designed to sustain loads or pressures, provide stiffness and stability, or provide support or containment.

STRUCTURE, PRIMARY

That part of a flight vehicle or element which sustains the significant applied loads and provides main load paths for distributing reactions to applied loads. Also the main structure which is required to sustain the significant applied loads, including pressure and thermal loads, and which if it fails creates a catastrophic hazard. If a component is small enough and in an environment where no serious threat is imposed if it breaks, then it is not primary structure.

STRUCTURE, SECONDARY

The internal or external structure which is used to attach small components, provide storage, and to make either an internal volume or external surface usable. Secondary structure attaches to and is supported by primary structure.

SYSTEM

Constellation Program physical entities that have functional capabilities allocated to them necessary to satisfy Architecture-level mission objectives. Systems can perform all allocated functions within a mission phase, or through mated operations with other Constellation Program systems (e.g. Crew Exploration Vehicle (CEV), Lunar Surface Access Module).

TAILORING

Adapting existing requirements to specific program or project needs.

TIME-CONSISTENT LOADS

See Loads, Time-Consistent

ULTIMATE LOAD, PRESSURE, OR STRESS

Ultimate Load, Pressure, or Stress - The maximum load, pressure, or stress that a structure shall withstand without incurring rupture or collapse; also, the product of the limit load multiplied by the ultimate FS. (Also Ultimate Strength.)

VALIDATION

(Product): Proof that the product accomplishes the intended purpose. Validation may be determined by a combination of test, analysis, and demonstration.

(Requirement): A process that ensures that requirements are well-formed (clear and un-ambiguous), complete (agrees with customer and stakeholder needs and expectations), consistent (conflict free), and individually verifiable and traceable to a higher-level requirement or goal.

(Models): TBD

VERIFICATION

A formal process, using the method of test, analysis, inspection or demonstration, to confirm that a system and its components satisfy all specified performance and operational requirements.

VERIFICATION TEST

Tests conducted on flight-quality structures at specified load levels to demonstrate that all structural design requirements have been achieved.

VIBRATION MODE

A characteristic pattern of displacement assumed by a vibrating system in which the motion of every particle is simple harmonic with the same frequency. Also referred to as Elastic Mode.

YIELD LOAD, PRESSURE, OR STRESS

The maximum load, pressure, or stress that a structure shall withstand without incurring detrimental deformations; analytically, the maximum load that a structure shall withstand without exceeding the yield stress of the material; also the product of the limit load multiplied by the yield FS. (Also Yield Strength.)

APPENDIX A
(DELETED)

APPENDIX B
(DELETED)