Structural Design and Verification Requirements

International Space Station

Revision D

July 27, 2007

NASDA

National Space Development Agency of Japan

Canadian Space Agency
Agence spatiale canadienne

agenzia spaziale italiana
(Italian Space Agency)

esa
european space agency

National Aeronautics and Space Administration
Space Station Program Office
Lyndon B. Johnson Space Center
Houston, Texas

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INTERNATIONAL SPACE STATION PROGRAM OFFICE

STRUCTURAL DESIGN AND VERIFICATION REQUIREMENTS

27 JULY 2007

PREFACE

SSP 30559, Structural Design and Verification Requirements, presents common structural design and verification requirements to ensure consistent design, development, and verification of International Space Station flight hardware.

Chapter 3.0 of this document describes general design requirements, design loads, factors of safety and margins of safety, design and stress analysis requirements, and structural materials criteria and discusses secondary structure accommodation for human interface and nonstandard fasteners. Chapter 4.0 contains verification requirements.

This document is under the control of the Space Station Control Board, and any changes or revisions will be approved by the Program Manager.

CONCURRENCE

INTERNATIONAL SPACE STATION PROGRAM

STRUCTURAL DESIGN AND VERIFICATION REQUIREMENTS

27 JULY 2007

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ref: SSP 50019, Para. 3.1.4.1 and JESA 30000, Section 3, Appendix B

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STRUCTURAL DESIGN AND VERIFICATION REQUIREMENTS

LIST OF CHANGES
27 JULY 2007

All changes to paragraphs, tables, and figures in this document are shown below:

SSCBD	ENTRY DATE	CHANGE	PARAGRAPHS
1285	07/27/07	2.0	Applicable Documents
		3.2.1	Shuttle Payload Configuration Design Loads
		3.5.7	Structural Life Requirements
		3.6.2.2	“B” And “S” Allowables
		4.1.4	Functional Configuration Audit/Physical configuration Audit
		4.1.4.3	Formal FCA/PCS Stress Report
		4.1.4.4	Stress Analysis For FCA/PCA
9111	07/27/07	3.8	Fastener Requirements
			TABLES
1285	07/27/07	3.3.1−1	Factors of Safety for Test Verified Structure
			FIGURES
			None
			APPENDIX
1285	07/27/07	Appendix A	Abbreviations and Acronyms
3286	07/27/07	D3.3.1	Factors of Safety − Test Verified Structure

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1.0 GENERAL

1.1 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 the Space Station 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.

1.2 PURPOSE

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

1.3 SCOPE

The requirements in this document shall apply to all Space Station flight hardware including all Program elements, Orbital Replacement Units, Orbital Support Equipment, Flight Support Equipment, and payloads.

1.4 INTENDED USE

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

1.5 APPROVAL BY NASA AND INTERNATIONAL PARTNERS

Structural design and verification approvals required by this document shall be as specified for each of the following categories:

1.5.1 INTERNAL TO USOS

For structures that are wholly internal to the U.S. On−orbit Segment (USOS), the National Aeronautics and Space Administration (NASA) shall provide the required approvals.

1.5.2 INTERNAL TO INTERNATIONAL SEGMENTS

For structures that are wholly internal to an International Segment, the International Partner responsible for that segment shall provide the required approvals.

1.5.3 SEGMENT TO SEGMENT INTERFACES

Structural design and verification approvals which affect segment to segment interfaces shall be obtained from both NASA and the affected International Partner.

1.5.4 OVERALL ISSA DESIGN AND VERIFICATION

Structural design and verification approvals which affect overall ISSA design and verification shall be obtained from NASA and all affected International Partners.

1.6 PRECEDENCE

SSP 41000, System Specification for the Space Station, defines the performance requirements for the Space Station and invokes this document for Space Station structural design and verification requirements. In the event of any conflict between SSP 41000 and this document, SSP 41000 takes precedence.

2.0 APPLICABLE DOCUMENTS

The following documents of the exact date and issue in SSP 50257 form a part of this document 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.

DOCUMENT NO.	TITLE
SSP 41000	System Specification for the Space Station
References	Paragraphs 1.6 and 3.1.5.1
SSP 30233	Space Station Requirements for Materials and Processes
References	Paragraph 3.6.1
SSP 30558	Fracture Control Requirements for Space Station
References	Paragraphs 3.1.3, 3.1.6, 3.1.9, 4.1.4, and Appendix B
SSP 30560	Glass, Window, and Ceramic Structural Design and Verification Requirements
References	Paragraph 3.1.7, and Table 3.3.1−1
D684−10019−01	Space Station Structural Loads Control Plan
References	Paragraph 3.2, 3.2.2, 3.2.3, 3.2.4.1, 3.2.4.2, and 4.2
MIL−HDBK−5	Metallic Materials and Elements for Aerospace Vehicle Structures
References	Paragraph 3.6.2, Appendix B
MIL−HDBK−17	Plastics for Aerospace Vehicles
References	Paragraph 3.6.2
SSP 50005	International Space Station Flight Crew Integration Standards (NASA−STD−3000/T)
References	Paragraph 3.1.5.2
NSTS−21000−IDD−ISS	Space Shuttle System Payload Accommodations
References	Paragraph 3.2.1
NSTS 08307	Criteria for Preloaded Bolts
References	Paragraph 3.5.5
NSTS 14046	Payload Verification Requirements
References	Paragraphs 4.1.2.1.1 and 4.1.3.1
20M02540	Assessment of Flexible Lines for Flow Induced Vibration
References	Paragraph 3.1.9.5
NSTS 08123	Certification of Flex Hose and Bellows for Flow Induced Vibration
References	Paragraph 3.1.9.5

MSFC−SPEC−626	Test Control Document for Assessment of Flexible Lines for Flow Induced Vibration
References	Paragraph 3.1.9.5

3.0 DESIGN REQUIREMENTS

3.1 GENERAL

3.1.1 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 Space Station flight hardware structure for both transport to and from orbit, and for on−orbit operations.

3.1.2 APPROVAL OF DETAILED DESIGN CRITERIA

Any detailed design criteria used by the responsible design organization shall be consistent with this requirements document. Detailed criteria which are not consistent with the requirements of this document shall be approved by NASA and/or International Partner.

3.1.3 STRENGTH AND STIFFNESS

Space Station structure shall have strength and stiffness in all necessary configurations and stages to support ultimate load without failure. Detrimental deformation shall not occur at limit loads imposed during Shuttle transportation and on−orbit operations, or during proof or acceptance testing. All flight primary structure shall be designed to be fail−safe, or have safe−life, or be a low risk fracture part as defined in SSP 30558, Fracture Control Requirements for Space Station.

3.1.3.1 ORBITER SAFETY

If, during assembly operations, an Orbiter payload element or its ASE is deployed, extended, or otherwise unstowed to a condition where it cannot withstand subsequent induced loads, there shall be two−failure tolerant design provisions to safe the Orbiter. Safing may include deployment, jettison, or provisions to change the configuration of the payload to eliminate the hazard.

3.1.4 THERMAL EFFECTS

Space Station shall meet its performance requirements when thermal effects are combined, when applicable, with induced static and dynamic loads.

3.1.4.1 CONTINGENCY DEORBIT THERMAL EFFECTS

Minimum design factor of safety for pressure vessels shall be maintained under conditions encountered at any continental United States or contingency landing site without postlanding services. Thermal analysis of postlanding conditions shall consider the following: a) worst−case Orbiter−induced initial conditions due to an abort from orbit to a contingency landing site with the payload subjected to the planned mission most−severe on−orbit thermal attitude; b) heat input from normal payload sources; c) heat input from up to two payload failures (Orbiter power busses are de−energized at landing plus 30 minutes.); and d) the envirionments defined in NSTS−21000−IDD−ISS.

3.1.5 DAMAGE TOLERANCE

3.1.5.1 EXTERNAL STRUCTURE DAMAGE TOLERANCE

Space Station mm/od critical flight structure shall be designed to meet the performance requirements when exposed to impacts by meteoroids and space debris as defined in SSP 41000. Space Station structure shall meet its performance requirements when exposed to EVA Crew Induced Loads defined in SSP 41000.

3.1.5.2 INTERNAL STRUCTURE DAMAGE TOLERANCE

Space Station internal structure shall meet its performance requirements when exposed to IVA crew induced loading as defined in SSP 50005, International Space Station Flight Crew Integration Standards.

3.1.6 FRACTURE CONTROL

The International Space Station shall be designed and verified for fracture control per the requirements of SSP 30558, Fracture Control Requirements for Space Station.

3.1.7 GLASS, WINDOW, AND CERAMIC DESIGN CRITERIA

The structural design and verification requirements for windows, glass, and ceramic structure shall be in accordance with SSP 30560, Glass, Window, and Ceramic Structural Design and Verification Requirements.

3.1.8 DESIGN REQUIREMENTS FOR SHUTTLE PAYLOADS

Space Station hardware in the Shuttle payload configuration shall meet Shuttle requirements for payloads as defined in NSTS−21000−IDD−ISS, Shuttle/Payload Interface Definition Document for International Space Station.

3.1.9 DESIGN REQUIREMENTS FOR PRESSURE SYSTEMS

3.1.9.1 FRACTURE CONTROL

Pressure vessels shall be designed and fabricated under an approved fracture control program and be in accordance with requirements specified in SSP 30558, Fracture Control Requirements for Space Station, Section 4.4.

3.1.9.2 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.

3.1.9.3 DEWARS

Dewar/cryostat systems shall be designed in accordance with the pressure vessel requirements in SSP 30558, section 4.4 and the following:

a) Pressure containers shall be leak−before−burst (LBB) designs where possible as determined by a fracture mechanics analysis. Containers of hazardous fluids and all non−LBB designs must employ a fracture mechanics safe−life approach to assure safety of operation.

b) MDP assessment for the pressure container shall envelop the pressure achieved under maximum venting conditions.

c) Outer shells (i.e., vacuum jackets) shall have pressure relief capability to preclude rupture in the event of pressure container leakage. If pressure containers do not vent external to the dewar but instead vent into the volume contained by the outer shell, the outer shell relief devices shall be capable of venting at a rate to release full flow without outer shell rupture. Relief devices shall be redundant and individually capable of full flow.

d) Pressure relief devices which limit maximum design pressure shall be certified to operate at the required conditions of use. Certification shall include testing of the same part number from the flight lot under the expected use conditions.

e) Nonhazardous fluids may be vented into the cargo bay if analysis shows that a worst case credible volume release will not affect the structural integrity or thermal capability of the Orbiter.

f) The proof test factor for each flight pressure container shall be a minimum of 1.1 times MDP. Qualification burst and pressure cycle testing is not required if all the requirements of 3.1.9 are met. The structural integrity for external loads shall be demonstrated in accordance with NSTS 14046.

3.1.9.4 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 shall be designed for safety consistent with structural requirements. Redundant seals in series which have been acceptance pressure tested individually prior to flight shall not be considered credible single barrier failures. 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. In order to be classified as a non−credible failure, the item shall be designed for a safety factor or 2.5 on the MDP, and shall be certified for all operating environments including fatigue conditions. If external leakage would not present a catastrophic hazard, the secondary volume shall either be vented or equipped with a relief provision in lieu of designing for system pressure.

3.1.9.5 FLOW INDUCED VIBRATION

All flexible hoses and bellows shall be designed to exclude or minimize flow induced vibrations in accordance with 20M02540. Certification of hardware shall be in accordance with NSTS 08123. When certification by test is required, requirements in MSFC−SPEC−626 shall apply.

3.1.9.6 PRESSURE STABILIZED VESSELS

Pressure vessels which are pressure−stabilized and must contain a minimum pressure to maintain the required ultimate factors of safety to insure structural integrity under launch and landing loads shall meet the following requirements:

The existence of the minimum required vessel pressure shall be verified prior to the application of safety critical loads into the system. This verification shall include a single fault tolerant 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.

3.1.9.7 BURST DISCS

When burst discs are used as the second and final control of pressure to meet the requirements of 3.1.9.2, they shall be designed to the following requirements:

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

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

c) Stress corrosion resistant materials shall be used for all parts under continuous load.

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

e) 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.

f) 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 or, (2) demonstration of a rigorous lot screening program approved by the Shuttle Payload Safety Review Panel.

3.1.10 STRUCTURAL DEGRADATION FROM MATERIAL EROSION

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

3.2 DESIGN LOADS

The Space Station shall meet its performance requirements 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. Limit load and load spectra shall be derived in accordance with the Space Station Structural Loads Control Plan, D684−10019−01.

Loads shall be generated for all significant forcing functions and appropriate combinations of forcing functions. Limit loads and load spectra shall be published for design and stress assessment. Load uncertainty factors for design and assessment may be used.

On−orbit structural design loads shall be defined to a 3 sigma level for limit load during the Program life for time−consistent loads. When time consistency is unknown, a 3 sigma equivalent load probability for each independent event on each type of load shall be used and load combinations shall be root sum square of the 3 sigma peak independent event consistent loads; or, a monte carlo analysis producing a 3 sigma load combination may be used. For major independent system failures, 2 sigma or equivalent loads shall be used. Random limit loads shall be defined as 3 sigma. A 3 sigma level shall be defined as a 99.73 percentile level for loads which are characterized by a 1−sided Gaussian or non−Gaussian distribution. A 2 sigma level shall be defined as a 95.45 percentile level for loads which are characterized by a 2−sided Gaussian distribution and a 97.72 percentile for loads which are characterized by a 1−sided Gaussian or non−Gaussian distribution. Launch transient and random vibration loads shall be derived in accordance with the Space Station Loads Control Plan, D684−10019−01.

3.2.1 SHUTTLE PAYLOAD CONFIGURATION DESIGN LOADS

For lift−off, ascent, on orbit, descent, and landing using Shuttle, Space Station structure shall be designed to maintain required functionality and positive margins when subjected to all static and dynamic loads and thermal environments as defined in NSTS 21000−IDD−ISS, Shuttle/Payload Interface Definition Document for International Space Station. Space Station structure shall be designed to maintain positive margins when subjected to emergency landing loads as defined in NSTS−21000−IDD−ISS.

3.2.2 INTEGRATED ON−ORBIT LOADS

The coordination, generation, and dissemination responsibility for Space Station on−orbit, integrated element interface loads is defined in the Space Station Structural Loads Control Plan, D684−10019−01.

For integrated on−orbit flight, ISS Program elements shall be designed to maintain required functionality and positive margins when subjected to all static and dynamic loads and thermal environments. All integrated on−orbit configurations from first launch through assembly complete configuration shall be considered.

3.2.3 DETAILED DESIGN LOADS

Detailed design loads shall be derived for all life cycles of hardware in accordance with the Space Station Structural Loads Control Plan, D684−10019−01.

3.2.4 MATH MODELS

3.2.4.1 ON−ORBIT FLIGHT HARDWARE LOADS MATH MODELS

Structural math models of on−orbit element flight hardware consistent with each phase of the Program shall be forwarded to the Prime Contractor in accordance with the Space Station Structural Loads Control Plan, D684−10019−01.

3.2.4.2 PAYLOAD MATH MODEL REQUIREMENTS

The Prime Contractor shall receive Shuttle payload math models in accordance with the Space Station Structural Loads Control Plan, D684−10019−01.

3.2.5 REDISTRIBUTED LOADS

Structures that are deployed, extended, or otherwise unstowed 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 3.3 on the redistributed loads after 1 or 2 credible system failures to the appropriate hazard levels. Operational procedures may be used to restore the load path or limit the applied loads after the first failure in order to maintain the required factors of safety.

3.3 FACTOR(S) OF SAFETY

3.3.1 FACTORS OF SAFETY − TEST VERIFIED STRUCTURE

All Space Station flight hardware structure shall be designed to the factors of safety (FS) specified in Table 3.3.1−1, Factors of Safety for Test Verified Structure, or as modified by the factors specified in paragraphs 3.0 and 4.0 of this document. See appendix D for the approved exceptions to this requirement.

TABLE 3.3.1−1 Factors of Safety for Test Verified Structure

		Yield	Ultimate
A. Minimum Factors of Safety for Metallic Flight Structures			
	Space Shuttle	1.0	1.4
	On−orbit	1.1	1.5
B. Minimum Factors of Safety for Non−metallic Flight Structures			
Non−discontinuity areas			
	Space Shuttle	N/A	1.4
	On−orbit	N/A	1.5
Discontinuity areas			
	Space Shuttle	N/A	2.0
	On−orbit	N/A	2.0
C. Minimum Factors of Safety for Pressure			
1. Design factors for windows, glass and ceramic structure are defined in SSP 30560, Glass, Window, and Ceramic Structural Design and Verification Requirements. The proof and ultimate factors for windows shall not be less than the following:			
Proof Pressure[1]		=2.00 X MDP	
Ultimate Pressure		=3.00 X MDP	
2. Engine Structures and Engine Compartments			

TABLE 3.3.1−1 Factors of Safety for Test Verified Structure

	Yield	Ultimate
Proof Pressure[1]	=1.50 X MDP	
Ultimate Pressure	=2.00 X MDP	
3. Hydraulic and Pneumatic Systems		
a. Lines and fittings less than 1.5 inches (38 mm) dia. (OD)		
Proof Pressure[1]	=1.50 X MDP	
Ultimate Pressure	=4.00 X MDP	
b. Lines and fittings, 1.5 inches (38 mm) dia. or greaer		
Proof Pressure[1]	=1.50 X MDP	
Ultimate Pressure	=2.00 X MDP	
c. Reservoirs/Presure Vessels		
Proof Pressure[1]	=1.50 X MDP	
Ultimate Pressure	=2.00 X MDP	
d. Actuating cylinders, valves, filters, switches, line−installed allignment bellows and heat pipes		
Proof Pressure[1]	=1.50 X MDP	
Ultimate Pressure	=2.50 X MDP	
e. Flex hoses, all diameters		
Proof Pressure[1,3]	=2.00 X MDP	
Ultimate Pressure	=4.00 X MDP	
4. Doors, Hatches and Habitable Modules		
a. Internal pressure only		
Proof Pressure[1]	=1.50 X MDP	
Yield Pressure	=1.65 X MDP	
Ultimate Pressure	=2.00 X MDP	
b. Negative pressure differential	=1.40 X differential pressure	
c. Combined loading conditions (Ref. NSTS 14046, paragraph 5.1.1.5c)		
5. Combined pressure and mechanical loading[2]		
	Yield	Ultimate
Space Shuttle	1.0(pressure+mechanical)	1.4(pressure+mechanical)
On−Orbit	1.1(pressure+mechanical)	1.5(pressure+mechanical)

Notes:

1. Proof factor determined from fracture mechanics service life analysis must be used if greater than minimum factor.
2. See paragraph 3.5.1.1 when pressure loads have a relieving or stabilizing effect on structural capability.
3. In a system with fluid lines and flex hoses, the individual flex hoses to be proof tested to 2.00 X MDP and the assembly level tested to 1.5 X MDP or proof factors as per note 1.

3.3.2 FACTORS OF SAFETY − ANALYSIS ONLY

3.3.2.1 SHUTTLE TRANSPORT TO/FROM ORBIT

For Space Shuttle payloads, verification of primary payload structure for strength integrity by analysis only is not considered to be a viable option without prior and written approval of the Space Shuttle/Payloads Structural/Mechanical Working Group.

3.3.2.1.1 EMERGENCY LANDING

The structural design shall comply with the ultimate design load factors for emergency landing loads that are specified in the ICDs between the Orbiter and the payload. Structural verification for these loads may be certified by analysis only.

3.3.2.1.2 NEGATIVE DIFFERENTIAL PRESSURE

Negative pressure differential on primary payload structure shall use an ultimate factor of safety of 2.0 if certification for these loads is by analysis only.

3.3.2.2 ON−ORBIT

For on−orbit loading conditions, structural verification using analysis only may be used where the type of structure is amenable to prediction of ultimate capability by analysis. This analysis−only option shall require increased factors of safety of 1.25 on yield and 2.0 on ultimate. Use of this option requires prior approval of NASA and/or International Partner.

3.3.3 HANDLING AND TRANSPORTATION

Flight structure design shall be based on flight loads and conditions rather than on transportation and handling loads, with the exception that handling attachment points for flight hardware may be designed locally for the handling loads at the attachment.

3.4 MARGIN(S) OF SAFETY

Space Station flight hardware structure shall have +0.00 or positive Margin(s) of Safety (MS) for all yield and ultimate design load conditions.

3.4.1 CRITERIA FOR LOCAL YIELDING

Local yielding of ISS structure shall be acceptable only if all of the following conditions are satisfied:

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

— There shall be no detrimental deformations which adversely affect the component/system function.

— The service life requirements are met.

3.5 DESIGN AND STRESS ANALYSIS REQUIREMENTS

3.5.1 STRESS/LOAD COMBINATION RESTRICTIONS

Structural margins of safety for yield and ultimate failure criteria shall be evaluated in order to ensure that adequate margin exists for the combination of mechanical, pressure, and thermal loads. Guidelines for combining mechanical loads may be found in NASA−TM−X−73305. The following restrictions shall be applied for load combinations.

3.5.1.1 COMBINING WITH PRESSURE STRESS/LOAD

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 and shall not be multiplied by the FS in calculating the design yield or ultimate load. Factors of safety for combined load conditions are defined in paragraph 3.3. For example, the ultimate compressive load in pressurized vehicle tankage shall be calculated as follows:

Ult Load = (FS X Mechanical Load) − (Min Pressure Load)

3.5.1.2 COMBINING WITH THERMAL STRESS/LOAD

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.

3.5.1.3 COMBINING LOW FREQUENCY AND RANDOM LOADS FOR COMPONENTS AND ATTACHMENTS

Low frequency loads and random vibroacoustic loads shall be combined according to Table 3.5.1.3−1, Load Combination Criteria for Components.

TABLE 3.5.1.3−1 Load Combination Criteria for Components

Axis	Steady State Load[1] (Limit)	Low Frequency Transient Load	Random Load
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	$QS_1 +/-(S_1^2 + R_1^2)^{1/2}$	+/− S_2	+/− S_3
2	+/− S_1	$QS_2 +/-(S_2^2 + R_2^2)^{1/2}$	+/− S_3
3	+/− S_1	+/− S_2	$QS_3 +/-(S_3^2 + R_3^2)^{1/2}$

Notes:
1. Resulting from 1.5 g’s in Orbiter negative X−axis
2. The loads calculated in a Space Shuttle/Payload coupled lift−off loads analysis include the low frequency transient and steady state effects, i.e. (S_i + QS_i)

3.5.2 BUCKLING AND CRIPPLING

Buckling shall not cause structural members that are subject to instability to collapse when ultimate loads are applied, nor shall buckling deformation from limit loads degrade the functioning of any system or produce unaccounted changes in loading.

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.

All structural components that are subject to compressive and/or shear in−plane stresses under any combination of ground loads, flight loads, or loads resulting from temperature changes shall consider buckling failure modes. 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 factor of safety. 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. Diagonal tension designs are not precluded.

Analyses of buckling of thin−walled shells shall use appropriate “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.

3.5.3 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. The drawing mean/average thickness may be used for stress calculations of all other structure. Actual as−built dimensions may be used in stress calculations when available.

3.5.4 DESIGN FACTORS

3.5.4.1 JOINT FITTING FACTOR

If required under the conditions outlined below, a fitting factor of 1.15 shall be used on yield and ultimate loads in the structural analysis of fittings.

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

3.5.4.2 BEARING FACTOR

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.

3.5.4.3 CASTING FACTOR

If metal castings are utilized as a fabrication process, an appropriate casting factor shall be developed by the design organization. The casting factor shall be applied in conjunction with the FS. Approval for the appropriate casting factor shall be obtained from NASA and/or International Partner. If a casting is a fitting, then the fitting factor shall be applied in conjunction with the casting factor and applied with the respective yield and ultimate FS.

3.5.5 PRELOADED JOINT CRITERIA

Bolt design in preloaded joints shall be in accordance with NSTS 08307, Criteria for Preloaded Bolts. Alternative methods to NSTS 08307 require prior NASA approval. A preloaded joint is a joint in which the preload is necessary to preserve linear structural behavior and to have adequate life due to cyclic loads, or to assure that no joint separation and resulting stiffness change occurs up to limit load, or to assure that no joint separation occurs at limit load which would affect pressure seals.

3.5.6 COMPOSITES/BONDED STRUCTURE DESIGN

Composite/bonded structure shall be designed to the factors of safety listed in Table 3.3.1−1, and to the life verification requirements of paragraph 4.1.3.4.

3.5.7 STRUCTURAL LIFE REQUIREMENTS

All structural components shall be evaluated for their capability to sustain static and cyclic load conditions which are part of the design environment. For those components whose design is subjected to a cyclic or repeated load condition, or a randomly varying load condition, a cyclic life analysis shall be performed.

Fracture analyses per the requirements of paragraph 3.1.6 shall be performed to demonstrate structural life for fracture critical structure. Fatigue or durability analyses shall be performed as necessary to demonstrate life for non−fracture critical structure. Structural life is defined as 4.0 times the service life loading environment for safe−life or fatigue analysis and 2.0 times the service life for durability analysis to account for material data scatter. The assumed flaw for durability analysis is a 0.005 inch corner crack or equivalent in the worst location and orientation.

3.5.7.1 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 or those specified in Table 3.3.1−1.

3.5.7.2 FATIGUE

All flight hardware structure shall be designed to preclude failure resulting from cumulative damage due to cyclic loading and sustained stress during the design service life. Structural life shall be demonstrated by analysis and/or test based on a rationally derived cyclic loading spectrum that includes Shuttle transport to and from orbit, on−orbit, transportation, and testing loads.

3.5.7.2.1 FATIGUE STRESS VERSUS CYCLE LIFE CURVE FACTOR

The limit stress/strain shall be multiplied by a minimum factor of 1.15 on typical properties or 1.0 on lower bound properties prior to entering the stress versus cycle life (S/N) design curve to determine the low−cycle/high−cycle life.

3.5.7.2.2 LIFE FACTOR

The low−cycle/high−cycle fatigue analysis shall demonstrate a minimum calculated life of 4.0 times the required service life.

3.5.7.2.3 STRESS CONCENTRATION FACTORS − FATIGUE ANALYSIS

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

3.5.7.3 CREEP ANALYSIS

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.

Materials shall be selected to preclude accumulated damage from creep in the Space Station environment. If selection of a structural material which exhibits creep phenomena in the Space Station environment is unavoidable, then NASA and/or International Partner approval shall be obtained prior to use. All structural elements subject to creep shall be assessed to demonstrate the following factors.

3.5.7.3.1 CREEP ANALYSIS FACTOR

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

3.5.7.3.2 CREEP LIFE FACTOR

The analysis shall demonstrate a minimum calculated life of 4.0 times the required service life.

3.5.7.4 SERVICE LIFE

The on−orbit design service life for Space Station structures shall be 15 years. Periodic inspection, maintenance, and replacement of parts, i.e., ORUs, may be used to attain the 15−year requirement but shall be used only with approval of NASA and/or the International Partner.

3.6 STRUCTURAL MATERIALS CRITERIA

3.6.1 STRUCTURAL MATERIAL SELECTION

Material selection and documentation requirements shall be as defined in SSP 30233, Space Station Requirements for Materials and Processes.

3.6.2 STRUCTURAL MATERIAL ALLOWABLE PROPERTIES

Space Station material structural properties in the design environment shall be determined from MIL−HDBK−5, Metallic Materials and Elements for Aerospace Vehicle Structures; MIL−HDBK−17, Plastics for Aerospace Vehicles; or other sources which provide reliable and statistically valid data. Structural material property data obtained specifically for Space Station shall be generated by the procedures outlined in MIL−HDBK−5.

3.6.2.1 “A” ALLOWABLES

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. Equivalent material properties shall be approved by NASA and/or the International Partner.

3.6.2.2 “B” AND “S” ALLOWABLES

Material “B” or “S” or equivalent allowable values may be used in redundant structure in which the failure of a component would result in a safe redistribution of applied loads to other load−carrying structure. MIL−HDBK−5 material “S” allowables may be used for materials in lieu of “A” or “B” allowables where batch lot acceptance testing is a procurement requirement. Equivalent material properties shall be approved by NASA and/or International Partner.

3.7 SECONDARY STRUCTURE ACCOMMODATION FOR HUMAN INTERFACE

3.7.1 INSPECTION, MAINTENANCE, AND REPAIR

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

3.7.2 INTERIOR CLOSE OUT

Close−out structure shall be used on the Space Station to prevent items from becoming lost in the low−gravity environment.

3.7.3 GROUND AND ON−ORBIT OPERATIONAL ACCESS DOORS

Secondary structures such as compartment doors and access panels which provide access shall be operational in both ground and Earth orbit environments.

3.8 FASTENER REQUIREMENTS

Threaded fasteners that perform a safety critical function shall incorporate two separate verifiable locking features. Preload may be used as one of the features combined with a conventional aerospace secondary locking feature that is positive locking, vibration rated, and verifiable. Fasteners that are used in joints that are subject to rotation during operation shall use at least one non−friction type−locking device. The principal objective is to prevent inadvertent back out of the fastener in the event of loss of preload, due to acoustic, thermal, cyclic loading, and vibration induced distortions produced by all mission phase environments. For the purpose of this requirement, a fastener, or group of fasteners, is considered to be performing a safety critical function if the loss of that fastener, or group of fasteners, could result in a catastrophic hazard including the generation of FOD in the Shuttle payload bay. For use of liquid−locking compounds in safety−critical fasteners, refer to SSP 30233, section 4.5.5.3.

NASA and/or International Partner approval shall be obtained for the use of nonstandard or specially manufactured fasteners.

4.0 VERIFICATION REQUIREMENTS

4.1 STRUCTURAL VERIFICATION REQUIREMENTS

The responsible organization shall show by analyses and sufficient tests that the hardware meets Program design requirements and has adequate strength, stiffness, service life, and integrity to assure function and personnel safety. The responsible organization shall submit stress analyses and verification test reports which will verify the capability of the respective flight hardware to meet the design requirements of this document.

4.1.1 STRUCTURAL VERIFICATION PLAN

A structural verification plan for the flight hardware shall be submitted to NASA and/or International Partner and coordinated with the Space Shuttle/Payloads Structural/Mechanical Working Group for Shuttle−launched ISSA hardware. The structural verification plan shall identify the methods of verification for each hardware element and shall identify the proposed development, verification, and qualification tests.

4.1.2 MATH MODEL VERIFICATION

Loads and deformations utilized in the Space Station Program verification shall be based on verified structural math models.

4.1.2.1 DYNAMIC LOADS MATH MODELS

4.1.2.1.1 NATIONAL SPACE TRANSPORTATION SYSTEM MATH MODELS

Dynamic math models of Shuttle−launched ISS cargo elements and on−orbit Shuttle−attached configurations shall be test−verified in accordance with NSTS 14046, Payload Verification Requirements.

4.1.2.1.2 ON−ORBIT MATH MODELS

The Prime Contractor shall develop a plan describing the methodology and additional testing on the ground and on−orbit, required to verify the integrated system math models.

4.1.2.2 STATIC INTERNAL LOADS MATH MODELS

The math models used to generate internal loads for structural analysis shall be verified by the methodology selected from the requirements in paragraph 4.1.3 of this requirements document.

4.1.3 STRENGTH AND LIFE VERIFICATION

The integrity of structure shall be verified by analysis or a combination of test and analysis.

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 and/or International Partner.

4.1.3.1 FOR SHUTTLE LOADS

The Space Station structural design and verification requirements for the transport phases to and from orbit shall be consistent with the requirements for Shuttle payloads specified in NSTS 14046. ISS elements shall be verified by test and/or analysis to the ascent vibro−acoustic environment defined in NSTS−21000−IDD−ISS.

4.1.3.2 FOR ON−ORBIT LOADS

Strength verification shall be demonstrated by analysis and successful completion of any one or a combination of the following options. Analysis−only strength verification requires prior approval of NASA and/or International Partner.

4.1.3.2.1 STATIC TEST TO ULTIMATE LOADS

For components whose critical failure modes result from on−orbit loads, 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 3.3.1−1. Sufficient instrumentation shall be utilized to identify high strain areas and verify that the internal loads distribution and displacements are consistent with the loads model and the internal loads model.

4.1.3.2.2 PROTOFLIGHT STATIC TEST

For structures whose critical failure modes result from on−orbit loads, protoflight structure shall be static tested to 1.2 times the design limit loads. Sufficient instrumentation shall be utilized to identify high strain areas and verify the internal loads distribution, displacements, and the internal loads model. The minimum yield factor of safety shall be 1.25 for the structure to be verified by this option. Use of this option requires prior approval of NASA and/or International Partner.

4.1.3.3 LIFE VERIFICATION

In addition to the foregoing static test options, the responsible organizations shall identify the approach for life verification for cyclic and sustained loads in the design environment, which includes atomic oxygen, plasma environmental effects incompatibilities, debris, and meteoroid environments.

4.1.3.4 LIFE VERIFICATION FOR COMPOSITE/BONDED STRUCTURE

4.1.3.4.1 GENERAL QUALITY REQUIREMENTS

All composite/bonded structures shall, as a minimum, meet prescribed structural verification requirements specified in this document. Furthermore, the designer/manufacturer shall use only manufacturing processes and controls (coupon tests, sampling techniques, etc.) that are demonstrated to be reliable and consistent with established aerospace industry practices for composite/bonded structures. Test articles shall be designed and fabricated to the same requirements, drawings, and specifications as the flight article.

4.1.3.4.2 COMPOSITE/BONDED FRACTURE CRITICAL STRUCTURE

Composite/bonded fracture critical structures shall be verified 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. The required life shall be demonstrated by analysis using test developed material data and by a damage tolerance test program using either flight like structure or samples with controlled flaws or damage duplicating the composite construction of the flight hardware. Damage tolerance data from previous programs may be used if shown to be applicable and approved by NASA and/or International Partner.

4.1.3.5 ACCEPTANCE TEST OF COMPOSITE/BONDED STRUCTURES

Acceptance of composite/bonded structures shall be by one of the following methods:

— An acceptance proof test shall be conducted to no less than 120 percent of the limit load. The proof test shall be conducted on each composite/bonded flight article. 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.

— Demonstration that the manufacturer of the composite article has a successful history of building a like design, certified and controlled specifications are used, personnel are properly trained and certified, and proposed nondestructive testing techniques are adequate to validate the quality and integrity of the hardware. This option must be supported by documentation demonstrating compliance with the listed criteria and approved by NASA and/or International Partner.

4.1.3.6 VERIFICATION OF BERYLLIUM STRUCTURES

Verification of Beryllium structures shall be in accordance with NSTS 14046, section 5.1.1.1.

4.1.4 FUNCTIONAL CONFIGURATION AUDIT/PHYSICAL CONFIGURATION AUDIT

The responsible design organizations shall provide stress analysis documentation of all structure to assure compliance with strength and deformation requirements. Stress analysis reports shall be submitted to NASA in support of the following four design reviews: Preliminary Design Review (PDR); Critical Design Review (CDR); Functional Configuration Audit/Physical Configuration Audit (FCA/PCA); and Flight Readiness Review (FRR), as delineated in the following paragraphs. These analyses shall be current with respect to loads and the design at the time of the review. Fatigue analyses shall be submitted with the stress analysis reports. Current stress analyses shall be available to support interim reviews. 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. 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.

4.1.4.1 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.

4.1.4.2 STRESS ANALYSIS FOR CRITICAL DESIGN REVIEW

This analysis shall fully substantiate the structural integrity of each detailed part and provide the basis for stress signatures required on all drawings. Life requirements shall be addressed in this analysis.

4.1.4.3 FORMAL FCA/PCA STRESS REPORT

A formal stress report shall be submitted to and approved by NASA and/or international partner prior to the FCA/PCA.

4.1.4.4 STRESS ANALYSIS FOR FCA/PCA

This analyses 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.

4.1.4.5 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 FCA/PCA.

4.1.5 STRUCTURAL VERIFICATION TESTS – PRIOR TO FLIGHT

4.1.5.1 GENERAL REQUIREMENTS

Dedicated structural verification tests are required unless protoflight tests are approved by the Prime Contractor. All test plans and requirements shall be coordinated with and approved by NASA and/or International Partner.

4.1.5.2 STRENGTH TESTS

Strength verification of primary structure shall be by static test. Test loads shall duplicate or envelop all flight loads and include pressure and temperature effects. When a separate verification structure (dedicated test article) is used, the tests shall be accomplished at the yield and ultimate levels specified by the required factors of safety.

Testing to an ultimate FS is for structural design verification only and not for attached systems. Unless otherwise specified, hydraulic, electrical, and other systems are not required to operate at loads and related deformations in excess of limit load or a constraint levied by the appropriate system.

4.1.5.2.1 DYNAMIC TESTS

Sinusoidal dynamic tests may be used when warranted by load conditions, test article size, and boundary conditions.

4.1.5.3 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.

4.1.5.4 TEST REPORTS

Qualification tests shall be documented. 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, and a summary of test data which is applicable to the strength verification.

4.1.5.5 ENGINEERING ANALYSIS REPORTS

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

4.2 LOAD VERIFICATION

Loads and load spectra used in establishing structural life shall be verified in accordance with the Space Station Structural Loads Control Plan, D684−10019−1.

4.3 STRUCTURAL 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 and/or International Partner.

APPENDIX A ABBREVIATIONS AND ACRONYMS

CDR	Critical Design Review
EVA	Extravehicular Activity
FCA	Functional Configuration Audit
FHA	Flexible Hose Assembly
FOS	Factor of Safety
FRR	Flight Readiness Review
HDBK	Handbook
IVA	Intravehicular Activity
ISS	International Space Station
ITS	Integrated Truss Segment
LBB	Leak Before Burst
MIL	Military
mm/od	Micro−Meteoroid / Orbital Debris
MDP	Maximum Design Pressure
MS	Margin of Safety
NASA	National Aeronautics and Space Administration
NDE	Non−Destructive Evaluation
NSTS	National Space Transportation System
ORU	Orbital Replacement Unit
PBA	Portable Breathing Apparatus
PCA	Physical Configuration Audit
PDR	Preliminary Design Review
psia	Pounds per square inch absolute
REV	Revision
SMART	Safety and Mission Assurance Review Team

S/N	Stress versus cycle life
SRP	Safety Review Panel
STD	Standard
SSCBD	Space Station Change Board Directive
SSCM	Space Station Change Memorandum
SSP	Space Station Program
TRRJ	Thermal Radiator Rotary Joint

APPENDIX B 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

Acceptance tests are used to verify and to demonstrate that the hardware is acceptable for flight and performs to specifications. It also serves as a quality screen to detect deficiencies, and to provide the basis for delivery of an end item(s) to the contract customer. Most acceptance tests include performance and functional testing, leak checks, proof pressure, random vibration, and thermal cycle tests.

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.

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 permit 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.

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.

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.

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.

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.

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.

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.

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 which assumes that fracture or failure of the part resulting from the occurence of a crack will result in a catastrophic hazard. Such classification is required on structural components unless the contrary is demonstrated using the criteria of paragraph 4.2 of SSP 30558.

FRACTURE MECHANICS

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

INITIAL FLAW SIZE

The maximum size of the flaw, 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.

LEAK BEFORE BURST

A fracture mechanics design concept in which it is shown that any initial flaw will grow through the wall of a pressure vessel and cause leakage rather than burst (catastrophic failure).

LIMIT LOAD OR STRESS

The maximum load or stress 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, 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, 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.

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:

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

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.

NON−SAFETY CRITICAL STRUCTURES

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

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.

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.

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.

RANDOM VIBRATION

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

ROTATING MACHINERY

Machinery which has rotating parts.

SAFE−LIFE

A design criterion under which a flaw is assumed consistent with the inspection process specified and it can be shown that the largest undetected flaw that could exist in the structure will not grow to failure in four service lifetimes when subjected to the cyclic and sustained loads in the environments encountered; also, the period of time for which the integrity of the structure can be ensured in the expected operating environments.

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, manufacturing process, and the loading environment.

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 including testing, transportation, lift−off, ascent, on−orbit operations, and descent and landing as applicable.

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, 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.

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.

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.)

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 C REFERENCE AND BIBLIOGRAPHIC DOCUMENTS

C.1 REFERENCE DOCUMENTS

C.1.1 NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

The documents in this paragraph are provided as reference material for background information only. In case of conflict this document shall take precedence.

DOCUMENT NO.	TITLE
JSC 19652A (Sept. 1987) Reference	Instructions for the Preparation of Stress Analysis Reports; Structural Mechanics Branch Report 4.1.4
NASA SP−8007 Reference	Buckling of Thin−Walled Circular Cylinders 3.5.2
NASA−TM−X−73305 (August 1975) Reference	Astronautics Structures Manual Volume I, Section A−3 3.5.1

C.2 BIBLIOGRAPHIC REFERENCE DOCUMENTS

1. Garba, J.A., Loads and Low Frequency Dynamics − An Environment Database, American Institute of Aeronautics and Astronautics, Report 10, 1988.
2. NASA MSFC SLP/2104−2, Spacelab Payload Accommodation Handbook, Rev. 3, 1986.
3. NASA MSFC JA−218 A8−89, Payload Flight Equipment Requirements for Safety Critical Structures, 1984.
4. Trubert, M.R., JPL−D−1347, Designing Galileo to Upper Bound Loads for Shuttle/Centaur, Proceedings of the Shuttle Payload Dynamic Envelope and Loads Prediction Workshop, Vol.II, pp. 617−664, 1984.
5. Hamilton, D.C., Wade, D.C., STS Payload Design Load Evolution, European Space Agency SP289, January 1989, Proceedings of the Spacecraft Structures and Mechanical Testing Conference, Oct. 1988, Nordwijk, The Netherlands.
6. Wada, B.W., Structural Qualification of Large Spacecraft, 1985, International Conference on Space Structures, Toulouse, France.
7. Chen, J.C., Evaluation of Modal Testing Methods, American Institute of Aeronautics and Astronautics, Report 1071, 1984.
8. Coleman, A.D., Anderson, J.B., Driskill, T.C., and Brown, D.L., A Mass Additive Method for Modal Testing as Applied to the Space Shuttle Astro−1 Payload, 1988, Proceedings of the Sixth International Modal Analysis Conference, Kissimmee, Florida.
9. Hamilton, D.A., JSC 20545A, Simplified Design Options for STS Payloads, August 1988.

10. Stroud, R.C., The Modal Survey of the Galileo Spacecraft, Sound and Vibration Journal, 1984.

11. NASA MSFC Technical Memo X73305, X73306, and X73307 Astronautics Structures Manual. Volumes 1, 2, and 3.

APPENDIX D APPROVED REQUIREMENTS EXCEPTIONS

D.1 SCOPE

This appendix modifies the applicability of the requirements contained in Sections 3.0 and 4.0 of this document. Corresponding paragraph numbers for which no limited applicability exists will not be included in this appendix.

D.2 APPENDIX STRUCTURE

The appendix is organized by ascending paragraph number. For example: paragraphs comprised of 3.2.1.X paragraph numbers appear in front of 3.2.2.X numbered paragraphs. Paragraph numbering corresponds to the main body paragraph, except for a leading “D” matching the designator of the appendix.

D.3 REQUIREMENTS

D3.3.1 FACTORS OF SAFETY – TEST VERIFIED STRUCTURE

A. Exception: The Integrated Truss Segment (ITS) S1, CI No. 222200A, and the ITS P1, CI Number 222260A, Thermal Radiator Rotary Joint (TRRJ) #1 and #2 Flexible Hose Assemblies (FHA) shall be designed for Proof Testing to 1.15 x MOP.

Rationale: The TRRJ FHA hoses were designed and produced under the Space Station Freedom program. The transition to ISS resulted in the system Maximum Operating Pressure (MOP) changing from 284 to 500 psi (proof changed from 568 to 1000 psig). The hoses have been exposed to a proof pressure of 575 psig without yielding. Prior to performing a development wear/life test, the hoses were proofed to 694 psig, causing yielding of the hose convolutes. The hoses have been exposed to a burst test resulting in rupture between 3046 and 3190 psig. The hoses are subjected to a pressure of 1100 to 1200 psi during the manufacturing “forming” process. The TRRJ FHA is non−fracture critical; hose failure results in a functional degradation and is not a safety issue. Screening for workmanship defects is adequate using a proof pressure of 575 psig along with two Non−Destructive Evaluation (NDE) inspection techniques (dye penetrant and x−ray). In addition, the manufacturing process has been controlled to ISS approved requirements.

Reference: SSCM000913, dated 04/13/98

B. Exception: The Node 1 Structural Assembly, CI No. 683052A, was tested to 1.05 x (pressure + on−orbit mechanical loads).

Rationale: The Node 1 Structural Test Article was not tested to 1.5 x (pressure +on−orbit mechanical) loads due to concerns at the time that such a test would damage a structure that was subsequently destined to be the Node 2 flight article. A test level of 1.05 x (pressure + on−orbit mechanical) load was determined to sufficiently exercise the structure such that ultimate load capability could be determined by analysis. The 1.05 x (pressure + on−orbit mechanical) load test was successfully performed and structural analysis based on the test−correlated Node structural math model has demonstrated positive margins of safety at 1.5 x (pressure + on−orbit mechanical loads).

Reference: SSCM001356, dated 08/12/98

C. Exception: Portable Breathing Apparatus (PBA) Oxygen Cylinder, P/N SEG33105011−301 is in noncompliance with the requirements of SSP 30559, for Factors of Safety (FOS) as follows:

(Ref. NCR−PBA−SP01). SSP 30559, Table 3.3.1−1 requires a proof factor of 1.50 X Maximum Design Pressure (MDP) and an ultimate FOS of 2.0 X MDP be maintained for pressure vessels.

The PBA oxygen cylinder MDP due to possible temperature excursions is 3400 psig, which is 400 psig above manufacturer's rating. Therefore, based on the 3400 psig MDP and the manufacturer's ratings, the PBA oxygen cylinder has a proof factor of 1.32 and an ultimate FOS of 1.76.

Rationale:

Without the exception, the hardware cannot be certified and provided to support ISS Program and meet Flight 4A−19A. Lowering the initial charge pressure in the PBA to maintain an MDP at or below manufacturer's rating to accommodate increased storage temperatures would result in less than a 15 minute supply of oxygen to the crewmember. An alternative would be to redesign the hardware/procure new hardware, if available, that meets the SSP 30559 requirements resulting in cost and schedule impacts.

The PBA is charged to 3000 psig at ambient temperature. However, the MDP of 3400 psig is based on the maximum temperature (120 degrees Fahrenheit) the PBA will be exposed to during its service life. An actual burst test conducted on two qualification units of the pressure vessel by the vendor (ARDE Inc) demonstrated a burst pressure of 6375 psig and 6420 psig respectively. This test demonstrates an ultimate safety factor of 1.88 with respect to MDP of 3400 psig.

All flight vessels have been subjected to a proof test at 4500 psig at ambient temperature and a proof test at cryogenic temperatures, which screens flaws both in the membrane and in the weld of the vessel. In light of this cryogenic proof test, NDE of the vessels and the lower proof factor at ambient temperatures are not of any technical significance. Analytically it has been shown that the pressure vessel has a safe−life for a minimum of 4 proof cycles (at 4500 psig) and 300 cycles at MDP (at 3400 psig). The anticipated cycle life for the PBA vessel is far less than 50 cycles (approximately 17 cycles at 3000 psig and 8 cycles at 3400 psig.) It has also been determined that the ultimate failure mode of the vessel is benign, i.e. it will leak and not rupture.

Based on the above information it has been concluded that the risk of the PBA pressure vessel failing due to non−compliance with safety factors and proof factors is very minimal and leakage is non−credible according to fracture mechanics analysis. Accepting this minimal risk ensures a 15 minute supply of oxygen to the crewmember when needed. The noncompliance has been reviewed by Safety (Safety and Mission Assurance Review Team (SMART) and Safety Review Panel (SRP)) and ISS Structures group. The exception is considered acceptable based on the rational provided. The option for resolving this issue is to approve CR 2058.

D. Exception: The PBA Reducer, P/N SEG33105014−301 is in noncompliance with the requirements of SSP 30559, for FOS as follows:

(Ref. NCR−PBA−SP02). SSP 30559, Table 3.3.1−1 requires a proof factor of 1.50 X MDP and an ultimate FOS of 2.5 x MDP be maintained for pressured components. The MDP SSP 30558 requires the same design and acceptance factors for fracture critical components.

The MDP on the high−pressure side of the reducer due to possible temperature excursions is 3400 psig. A pressure test was conducted at 7735 psig demonstrating an ultimate factor of safety of 2.28. The flight units for the PBA were acceptance tested to a minimum of 4650 psig.

Based on an MDP of 3400 psig, this is a proof factor of only 1.37, which is non−compliant with SSP 30559 and SSP 30558.

Rationale:

Without the exception, the hardware cannot be certified and provided to support ISS Program and meet Flight 4A−19A. An alternative would be to redesign the hardware/procure new hardware, if available, that meets the SSP 30559 requirements resulting in cost and schedule impacts.

Vendor rating for the reducer is 3100 psig. Analytical assessment suggests an actual burst capability in excess of 8500 psig. This information indicates a relatively low operation stress in the component as compared to its ultimate strength and compliance with ultimate FOS requirements.

The Monel material of the reducer has excellent fracture toughness properties and a high tolerance for flaws, i.e. a very large and extremely unlikely flaw would be necessary to result in leakage. The relatively low stress in the part and the essentially non−cyclical application further enhance the high probability that a non−leaking reducer will not leak during service. The systems will be leak checked prior to shipment.

The intent of a proof test of components, lines, and fittings is generally to screen critical flaws and/or retard growth of any existing flaws. Because of the characteristics mentioned above the proof test to a factor of 1.37 meets the full intent of fracture control for the PBA reducer.

The noncompliance has been reviewed by Safety (SMART and SRP) and ISS Structures group. The deviation is considered acceptable based on the rational provided. The option for resolving this issue is to approve CR 2059.

E. Exception: The PBA Mask Hose, P/N SEG33105020−301 is in noncompliance with the requirements of SSP 30559, for FOS as follows:

(Ref. NCR−PBA−SP03 SSP 30559), Table 3.3.1−1 requires a proof factor of 2.00 X MDP and an ultimate factor of safety (FOS) of 4.0 X MDP be maintained for hoses. The SSP 30559 proof factor requirement has been reduced to 1.5 by the ISS Program via CR number 1285. SSP 30558 requires the same design and acceptance factors for fracture critical lines.

The mask hose MDP is defined as 180 psig because the mask relief valve relieves at this pressure after two upstream failures occur. This two−fault failure mode occurs when the system pressure is coming from the PBA cylinder. (When hardlined to Station, the two fault tolerant max pressure is 140 psig, which meets appropriate FOS. Therefore, an Non−Conformance Report (NCR) is not needed for this operational mode.)

Based on the 180 psig MDP, the PBA mask hose has an ultimate FOS of 3.22. (The mask hose meets the proof rating requirement of SSP 30559 and SSP 30558.)

Rationale:

Without the exception, the hardware cannot be certified and provided to support ISS Program and meet Flight 4A−19A. An alternative would be to redesign the hardware/procure new hardware, if available, that meets the SSP 30559 requirements resulting in cost and schedule impacts.

The PBA mask hose is a flex hose made of a Silicone inner tube with a Nomex overbraid. Vendor test data indicates that the hose failed at 580 psig in a benign fashion demonstration a safety factor of 3.22 with respect to a MDP of 180 psig. The hose is exposed to a pressure of 180 psig only if both the regulator and the relief valve upstream fail to function. The pressure of 180 psig is based on the relief valve setting associated with the mask downstream of the hose. The flight hose has successfully passed a proof test to 2 x MDP (360 psig) and a leak check. The hose is pressurized only when the PBA is used by a crewmember. This implies that there is no forcing function that would cause the hose to fail after its pressure and leakage integrity have been verified on the ground. Under these circumstances, the risk of the hose failing due to non−compliance with safety factors is very minimal.

The mask is a unique kind of pressurized equipment that is assured safe by materials and quality control, which is typically provided by the vendor. A proof pressure test should not be expected and would serve no identifiable technical or safety purpose.

The noncompliance has been reviewed by Safety (SMART and SRP) and ISS Structures group. The deviation is considered acceptable based on the rational provided. The option for resolving this issue is to approve CR 2060.