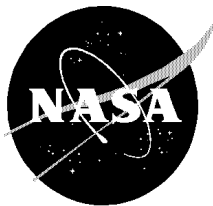


STRUCTURAL DESIGN REQUIREMENTS AND FACTORS OF SAFETY FOR SPACEFLIGHT HARDWARE

FOR HUMAN SPACEFLIGHT

OCTOBER 2011



National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center
Houston, Texas

*This document represents the technical consensus of the
developing group but does not yet have final NASA approval.*

Structural Design Requirements and Factors of Safety for Spaceflight Hardware For Human Spaceflight

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REVISION HISTORY AND CHANGE LOG

Rev.	Date	Originator	Description	Approval
Draft	4/28/2010	K. S. Bernstein	RFI Release 1 (Initial version of document to support RFI release of Commercial Crew Transportation Request for Information)	
Baseline	1/31/2011	K. S. Bernstein	- An applicable document number was updated from JSC-65830 to NASA-STD-5020 and the title of the applicable document was revised. - Some of the content regarding structural design requirements for solid rocket motors was clarified. - "Derating" was changed to "design" in the section on fabric structures, and the definition of "derating" was removed from the glossary in section B. - The definition of "A basis" was revised in section B.	
A	10/21/2011	K. S. Bernstein	A change was made to the call-out for AIAA standards S-80 and S-081, which address metallic pressure vessels and composite overwrap pressure vessels. The words "the design requirements specified in" were deleted from each callout. Vendors are expected to use the entire standard, tailored at the point of application. In addition, this release of the document includes format changes to comply with configuration management processes at JSC, and editorial changes in the Forward to update the description of the document. The references to JSC 62550 were updated to NASA-STD-5018, which had not been released when the structures standard was first published. The references to NASA-STD-5020 were reverted back to JSC 65830 because the NASA standard has not yet been released. Reference to the upcoming standard was added as a comment to the requirement. The references to JSC 65831 were updated to NASA-STD-5019, which had not been released when the structures standard was first published.	ES CCB

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Note: Dates reflect latest signature date of Revision.

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FORWARD

This is a standard published by the National Aeronautics and Space Administration (NASA) Johnson Space Center (JSC) that is intended to provide uniform structural design and factor of safety requirements in support of the development of human-rated spaceflight hardware. The material covered in this standard is based on the consensus judgment of a working group of structural engineers supporting the NASA JSC Structural Engineering Division, and founded on agency-wide consensus positions developed under the Constellation Program and lessons learned by the Space Shuttle Program's Structures Working Group.

The technical content of this standard is primarily based on the Constellation Program Structural Design and Verification Requirements (SDVR) document, CxP 70135 Change 004. It incorporates lessons learned from implementation of the SDVR within the CxP Orion and Ares projects, which highlighted a number of issues. The goal in writing this new standard was to maintain intent of the original requirement while reorganizing the content to improve document structure, clarify intent or remove redundancy. In some cases, requirements were removed because they are addressed in other standards being released concurrently, for example the new standard for fasteners and mechanical joints. In addition, detailed rationale statements were added for each requirement to provide guidance on interpretation and, in some cases, a discussion of the recommended verification method.

This standard focuses on design and factor of safety requirements. Details related to methods of verification of each requirement will be negotiated and approved via the structural verification plan submitted to the Technical Authority at the responsible NASA center for review and approval.

This standard was compiled with contributions from Rod Kujala/JSC, Karen Bernstein/JSC, Vince Fogt/JSC and Paul Romine/JSC.

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1 INTRODUCTION

1.1 PURPOSE

This document establishes the structural requirements for human-rated spaceflight hardware including launch vehicles, spacecraft and payloads. These requirements are applicable to Government Furnished Equipment activities as well as all related contractor, subcontractor and commercial efforts. These requirements are not imposed on systems other than human-rated spacecraft, such as ground test articles, but may be tailored for use in specific cases where it is prudent to do so such as for personnel safety or when assets are at risk.

The requirements in this document are focused on design rather than verification. Implementation of the requirements is expected to be described in a Structural Verification Plan (SVP), which should describe the verification of each structural item for the applicable requirements. The SVP may also document unique verifications that meet or exceed these requirements with NASA Technical Authority approval.

1.2 APPLICABILITY

This document recommends engineering practices for NASA programs and projects. It may be cited in contract, program, and other Agency documents as a technical requirement.

Determining the suitability of this standard and its provisions is the responsibility of program/project management and the performing organization. This standard is applicable to the development of new hardware. Applicability to existing hardware with previous flight history will be addressed in the program Systems Requirements Document (SRD). Project-specific tailoring may generate other project-specific requirements that are derivatives of this standard.

Other program standards such as International Space Station (ISS) requirements may also be applicable. For ISS specific events refer to the SSP 50808, International Space Station (ISS) to Commercial Orbital Transportation Services (COTS) Interface Requirements Document (IRD).

The requirements specifically excluded from this standard are materials and processes, design loads determination, fracture control, glass, fasteners, liquid propulsion engines greater than 6000 lbs thrust, ISS specific events, ground support equipment and facilities. Appropriate standards should be used for these topics, as applicable.

The scope of this document is to define the structural design requirements for primary and secondary structures sometimes also called safety critical structures.

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1.3 IMPLEMENTATION

The convention used in this document to distinguish between requirements and goals is as follows: “shall” is used to indicate requirements that must be implemented and verified, and “should” is used to indicate goals that must be addressed by the design but do not need to be verified. Each “shall” requirement is contained in its own subsection and indicated with a unique number using the format: [STRxxxx] for traceability purposes.

The purpose of the Rationale statement is to indicate why the requirement is needed, the basis for its inclusion in a requirements document, and to provide context and examples to stakeholders. It is important to note that the rationales are not binding and only provide supporting information.

1.3.1 Tailoring

The responsible NASA Center will charter a Loads and Structures Panel (LSP) for reviewing and approving the implementation of the requirements of this document. The LSP is the responsible NASA Technical Authority for the program for structural design requirements.

In the event that a particular requirement of this document cannot be met for a specific component, alternative tailored requirements may be proposed. Tailored requirements must be demonstrated to be “risk neutral” per the program risk assessment process. Risk neutral approaches have equivalent risk to the requirements in this document. The approach will be approved by the NASA LSP and documented in the SVP.

1.4 CONSTRAINTS AND PRECONDITIONS

The criteria of this document were developed in the context of structural designs that are amenable to engineering analyses by current state-of-the-art methods and conforming to standard aerospace industry practices. More specifically, the designs are assumed to use materials having mechanical properties that are well characterized for the intended service environments and all design conditions. For reusable and multi-mission hardware, these criteria are applicable throughout the service life and all of the missions.

Design considerations should include material property degradation under the service environments. Material allowables should be chosen to minimize the probability of structural failure due to material variability. Allowables should be based on sufficient material tests to establish values on a statistical basis. Further, the service environments and limit loads should be well defined. Aerospace standard manufacturing and process controls should be used in hardware fabrication and handling. Test hardware should be representative of the flight configuration.

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2 DOCUMENTS

The documents listed as applicable documents contain provisions that constitute requirements of this standard as cited in the text of Section 3. Reference documents are provided for additional information or to provide guidance to meet the requirements in Section 3 but are not levied as requirements.

The applicable documents are accessible via the NASA Technical Standards System at <http://standards.nasa.gov> or may be obtained directly from the Standards Developing Organizations or other document distributors.

2.1 APPLICABLE DOCUMENTS

ANSI/AIAA S-080-1998	Space Systems - Metallic Pressure Vessels, Pressurized Structures, and Pressure Components, September 13, 1999
ANSI/AIAA S-081A-2006	Space Systems - Composite Overwrapped Pressure Vessels (COPVs), July 24, 2006
JSC 65829	Loads and Structural Dynamics Requirements for Spaceflight Hardware
JSC 65830, rev. 2	Interim Requirements and Standard Practices for Mechanical Joints with Threaded Fasteners in Spaceflight Hardware
NASA-STD-5019	Fracture Control Requirements for Spaceflight Hardware
NASA-STD-5012	Strength and Life Assessment Requirements for Liquid Fueled Space Propulsion System Engines, Baseline, June 13, 2006

2.2 REFERENCE DOCUMENTS

AIAA S-110-2005	Space Systems – Structures, Structural Components, and Structural Assemblies, July 12, 2005
DOT/FAA/AR-MMPDS-01	Metallic Materials Properties Development and Standardization, January 2003
JSC 19652	Instructions for the preparation of Stress Analysis Reports, Revision A, September 1987
MIL-DTL-83420M	Wire Rope, Flexible, for Aircraft Control, General Specification for, w/ Amendment 1, February 17, 2009
MSFC-DWG-20M02540	Assessment of Flexible Lines for Flow Induced Vibration, Revision E, Jan 15, 1992
MSFC-SPEC-626	Test Control Document for Assessment of Flexible Lines for Flow Induced Vibration, February 28, 1990

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MIL-HDBK-17-2	Composite Materials Handbook Volume 2, Polymer Matrix Composites Materials Properties, Revision F, June 17, 2002
MIL-HDBK-17-4	Composite Materials Handbook Volume 4, Metal Matrix Composites, Revision A, June 17, 2002
MIL-HDBK-17-5	Composite Materials Handbook Volume 5, Ceramic Matrix Composites, June 17, 2002
NASA SP-8007	Buckling of Thin-Walled Circular Cylinders, September 1965
NASA-STD-5018	Strength Design and Verification Criteria for Glass, Ceramics and Windows in Human Space Flight Applications, September 2006
NASA-STD-5020	Requirements and Standard Practices for Mechanical Joints with Threaded Fasteners in Spaceflight Hardware
NASA-STD-6016	Standard Materials and Processes Requirements for Spacecraft, Baseline, July 11, 2008
NASA-TM-X-73305	Astronautic Structures Manual, August 1975
NSTS 08123	Certification of Flex Hoses and Bellows for Flow Induced Vibration, Revision C, April 12, 1994
NSTS/ISS 18798	Interpretations of NSTS/ISS Payload Safety Requirements, Revision B, September 1997
NWC TP 6575	Parachute Recovery Systems Design Manual, March 1991
SMC-S-005	Space and Missile Systems Center Standard, Space Systems – Flight Pressurized Systems, June 3, 2009
SSP 50808	International Space Station (ISS) to Commercial Orbital Transportation Services (COTS) Interface Requirements Document (IRD), Revision A, May 9, 2008.

2.3 ORDER OF PRECEDENCE

This document establishes requirements for structural design and test factors but these factors do not supersede or waive established Agency requirements found in other documentation. Conflicts between this standard and other requirements documents will be resolved by the NASA Technical Authority.

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3 STRUCTURAL REQUIREMENTS

3.1 STRUCTURAL ASSESSMENT PROGRAM

3.1.1 Structural Verification Plan

[STR0001] The organization responsible for structural design shall develop and maintain a comprehensive Structural Verification Plan (SVP) that documents the full structural analysis, test, and assessment program for approval by the NASA Technical Authority.

Rationale: The purpose of this plan is to establish an understanding and agreement between the organization responsible for structural design and the NASA Technical Authority. The SVP development, negotiation and approval process serves as the means to tailor the design requirements for their unique application to each design and organization, ensuring the meet-or-exceed implementation of the requirements as described in Section 1.4.

A comprehensive SVP specifies how the design requirements of this document will be met and verified. It demonstrates that the organization responsible for design and development understands all relevant requirements and has implemented them in a consistent and integrated manner. The SVP will identify the analyses, tests, inspections, demonstrations or appropriate combinations of these that comprise verification of the requirements in this document.

The content and format of the SVP is not formally defined; however the document should include the following as a minimum;

- a. A requirements applicability matrix that identifies which requirements are applicable to the system or hardware being delivered and rationale for exclusion if not levied.*
- b. A list of applicable requirements documents.*
- c. A brief description and sketches of hardware primary and secondary structure.*
- d. The proposed method for verification of the primary and secondary structure items. Include proposed factors of safety, stress analysis methodology (i.e., hand or computer analysis), verification approach for the analytical models that will be used for stress calculations, and the proposed strength testing. Rationale must be provided if no strength testing is planned.*
- e. Description of special materials (e.g., composites, beryllium, and glass) and the corresponding special measures which will be taken to verify their strength according to the requirements of this or other applicable requirements documents*
- f. Brief description of the source of material allowables which will be used for the strength analysis for each primary and secondary structure item.*
- g. Specific implementation of fastener and preloaded joint requirements as defined in JSC 65830, rev. 2.*

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- h. Derivation of design loads for primary structure, secondary structure, and components or experiments as described in JSC 65829.*
- i. Proposed method for dynamic math model verification of the primary and significant secondary structural hardware as defined in JSC 65829. Rationale must be provided if no dynamic testing is planned.*
- j. Summary and schedule of all loads and stress analyses, planned tests (includes strength, pressure, dynamic, random vibration, and acoustic tests), and math model correlation activities as described in this document and other relevant specifications.*

The initial delivery of the SVP should be at the Preliminary Design Review (PDR). The fidelity at PDR should be detailed enough to define the structural verification approach including planned development testing. The SVP must be maintained and updated because the hardware design and the design data will evolve as the data such as loads, mass properties, temperatures and other environments are verified. The SVP should be updated between PDR and CDR to support these evolutions and to update the structural verification approach, as needed. By CDR, the SVP should be finalized and approved by the NASA Technical Authority.

It is probable that the design database will mature after Critical Design Review (CDR), and design changes will need to be considered in response to these developments. The organization responsible for structural design will need to establish a program to evaluate how post-CDR changes in the natural and induced environments may affect the hardware and the type of document updates that will be provided.

3.1.2 Stress Analysis

[STR0002] Design stress analysis reports, including a margin of safety summary table and an indentured parts list, shall be prepared in accordance with standard aerospace industry practices for flight hardware and available for review by the NASA Technical Authority.

Rationale: The stress analysis report will document analysis results and conclusions. The purpose of the stress analysis report is to verify the capability of the respective flight hardware to meet the design requirements specified in this document. At a minimum, content similar to that summarized in JSC 19652, Instructions for the preparation of Stress Analysis Reports, should be included.

The margin of safety summary table shows the minimum margin of safety for the flight vehicle or element structure, the critical condition or mode of failure and the critical load for the flight vehicle or element structure.

An indentured parts list identifies each and every part of the vehicle. If parts are non-structural or acceptable by inspection, the summary should state so. If a part is accepted by similarity to other parts, the summary table should indicate this clearly.

Stress analysis reports are typically prepared 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).

3.1.3 Structural Test Plans

[STR0003] 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 the NASA Technical Authority for each unique structural test.

Rationale: The SVP should describe the structural tests that will be performed and identify which test plans will be submitted to the NASA Technical Authority. Test plans for qualification tests, proof tests and model verification are generally covered by this requirement.

The test plan includes 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 and the stresses and forces compared to predicted flight conditions.

3.1.4 Structural Test Reports

[STR0004] A test report showing the results of each unique structural test shall be prepared and submitted to the NASA Technical Authority.

Rationale: The test report includes stresses and forces developed during test and a summary of test data which is applicable to the structural verification. The report should also include a comparison of the test results to the analysis of the test configuration, demonstrating that the test objectives were met.

3.2 STRUCTURAL DESIGN

Structures are components and assemblies designed to sustain loads or pressures, provide stiffness and stability, or provide support or containment. Internal components are excluded if their failure would not result in a critical or catastrophic hazard.

3.2.1 Structural Strength

3.2.1.1 Ultimate Structural Strength

[STR0005] Flight hardware structure shall maintain structural integrity with +0.00 or positive Margin(s) of Safety (MS) when exposed to limit loads multiplied by ultimate factors of safety during the service life, including the effect of aging on the hardware.

Rationale: Structural integrity is lost when the structure can no longer maintain its load-carrying capacity.

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Limit loads multiplied by ultimate factors of safety are sometimes called “ultimate loads”.

Aging is intended to account for degradation of mechanical properties due to service life environments, such as potential structural erosion caused by plasma environmental effects, atomic oxygen, and other natural environments, during the design life.

Factor of safety requirements are contained in Section 3.3.1.

A definition of service life is provided in Section B.

3.2.1.2 Detrimental Deformation

[STR0006] Flight hardware structure shall have no detrimental deformation when exposed to limit loads multiplied by yield factors of safety during its service life.

Rationale: *Detrimental deformation is structural deformation, deflection, or displacement which causes any of the following:*

- a. Causes unintentional contact, misalignment, or divergence between adjacent components*
- b. Causes significant internal load redistribution in a structure*
- c. Causes a component to exceed the dynamic space envelop established for that component*
- d. Reduces the strength or rated life of the structure below specified levels*
- e. Degrades the effectiveness of thermal protection coatings or shields*
- f. Jeopardizes the proper functioning of equipment*
- g. Endangers personnel*
- h. Degrades the aerodynamic or functional characteristics of the vehicle*
- i. Reduces confidence below acceptable levels in the ability to ensure flight-worthiness by use of established analytical or test techniques*
- j. Induces leakage above specified rates*

Protoflight hardware structure will have no detrimental deformation when exposed to acceptance or proof test loads.

3.2.1.3 Yielding during Ground Transportation

[STR0007] Flight hardware structure shall not yield when exposed to ground limit loads multiplied by yield factors of safety during ground transportation, rollout or handling operations.

Rationale: *Yielding of the hardware during transportation could damage the structure, rendering the service life inadequate. Loads during ground*