

Standard

Space Systems – Structures, Structural Components, and Structural Assemblies

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Standard

Space Systems — Structures, Structural Components, and Structural Assemblies

Sponsored by

American Institute of Aeronautics and Astronautics

Approved

12 July 2005

Abstract

This document establishes a standard for the design, analysis, material selection and characterization, fabrication, test, and inspection of structural items in space systems, including payloads, spacecraft, upper-stages, and expendable and reusable launch vehicles. This standard, when implemented on a particular space system, will assure high confidence in achieving safe, reliable operation in all phases of the mission. This document applies specifically to all structural items including fracture-critical hardware used in space systems during all phases of the mission—with the following exceptions: adaptive structures, engines, solid rocket nozzles, and thermal protection systems.

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Foreword

This standard was prepared by the AIAA Structures Committee of Standards (CoS) based on an Aerospace Technical Operating Report, TOR-2003 (8583)-2894, Space Systems-Structures Design and Test Requirements, 2 August 2004.

The AIAA Structures CoS was formed in 2004 with an emphasis on inclusion of experts in aerospace industry, academia, and interested government agencies. Deliberations focused heavily on adapting this standard to new space systems not only developed for the United States Air Force/Space and Missile Systems Center (USAF/SMC) but also for civil and commercial applications.

At the time of approval, the members of the AIAA Structures CoS were:

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The above consensus body approved this document in June 2005.

The AIAA Standards Executive Council (Mr. Amr ElSawy, Chairman) accepted the document for publication in July 2005.

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1 Scope

This document establishes a standard for the design, analysis, material selection and characterization, fabrication, test, and inspection of structural items in space systems, including payloads, spacecraft, upper-stages, and expendable and reusable launch vehicles. This standard, when implemented on a particular space system, will assure high confidence in achieving safe, reliable operation in all phases of the mission. This document applies specifically to all structural items including fracture-critical hardware used in space systems during all phases of the mission—with the following exceptions: adaptive structures, engines, solid rocket nozzles, and thermal protection systems.

2 Tailoring

For a specific program or project, the requirements defined in this Standard may be tailored to match the actual requirements of the particular program or project. Tailoring of requirements shall be undertaken in agreement with the procuring authority where applicable.

Tailoring is a process by which individual requirements or specifications, standards, and related documents are evaluated and made applicable to a specific program or project by selection, and in some exceptional cases, modification and addition of requirements in the standards.

3 Applicable Documents

The following applicable documents contain provisions which, through reference in this text, constitute provisions of this standard.

Aerospace TOR-2003 (8583) - 2886	<i>Aerospace Technical Operating Report, Independent Structural Loads Analyses of Integrated Spacecraft/Launch Vehicle Systems</i>
ANSI/AIAA S-080	<i>Space Systems - Metallic Pressure Vessels, Pressurized Structures, and Pressure Components</i>
ANSI/AIAA S-081	<i>Space Systems - Composite Overwrapped Pressure Vessel (COPVs)</i>
ANSI/AIAA S-096	<i>Space Systems - Flywheel Rotor Assemblies</i>
ASTM E-8	<i>Test Methods for Tension of Metallic Materials</i>
ASTM E-9	<i>Test Methods for Compression Testing of Metallic Materials at Room Temperature</i>
ASTM E-399	<i>Test Method for Plane Strain Fracture Toughness of Metallic Materials</i>
ASTM E-647	<i>Test Method for Measurement of Fatigue Crack Growth Rates</i>
ASTM E-740	<i>Practice for Fracture Testing with Surface-Crack Tension Specimens</i>
DOD/NASA	<i>Advanced Composites Design Guide, Vols. 1-4</i>
DOT/FAA/AR-MMPDS-01	<i>Metallic Materials Properties Development and Standardization</i>
ISO 21347	<i>Space Systems-Fracture and Damage Control</i>
MIL-HDBK-17	<i>Military Handbook, Polymer Matrix Composites, Vols. 1-5</i>

MIL-STD-1540	<i>Military Standard, Test Requirements for Launch, Upper Stage, and Space Vehicles</i>
MCIC-HB-01	<i>Damage Tolerance Design Handbook</i>
NASA-STD-5002	<i>Loads Analysis of Spacecraft and Payloads</i>
NASA-STD-5007	<i>General Fracture Control Requirements for Manned Spaceflight Systems</i>
NSS 1740.14	<i>Guidelines and Assessment Procedures for Limiting Orbital Debris</i>

4 Vocabulary

4.1 Acronyms and Abbreviated Terms

ϵ -N	Fatigue Strain-Life Data
$\Sigma n/N$	Miner's rule
AIAA	American Institute of Aeronautics and Astronautics
ANSI	American National Standard Institute
ASTM	American Society for Testing and Materials
COPV	Composite Overwrapped Pressure Vessel
da/dN	Fatigue crack growth rate
CINDAS	Center for Information and Numerical Data Analysis and Synthesis
DOD	Department of Defense
DOT/FAA/AR	Department of Transportation/Federal Aviation Administration/Aviation Research
EVA	Extra-Vehicular Activity
FS	Factor of Safety
HDBK	Handbook
Hz	Hertz
ICD	Interface Control Document
ISO	International Organization for Standardization
KPP	Key Process Parameter
LBB	Leak-Before-Burst
MCIC	Metals and Ceramics Information Center
MEOP	Maximum Expected Operating Pressure
MEOS	Maximum Expected Operating Speed
MIL	Military

MMPDS	Metallic Materials Properties Development and Standardization
M/OD	Meteoroid and Orbital Debris
MS	Margin of Safety
NASA	National Aeronautics and Space Administration
NDE	Nondestructive Evaluation (Examination)
NDI	Nondestructive Inspection
NSS	NASA Safety Standard
S-N	Fatigue Stress-Life Data
VDT	Visual Damage Threshold

4.2 Terms and Definitions

For the purposes of this document, the following terms and definitions apply.

A-Basis Allowable

the mechanical strength value above which at least 99% of the population of values is expected to fall, with a confidence level of 95%

Acceptance Tests

formal tests conducted on flight hardware to ascertain that the materials, manufacturing processes, and workmanship meet specifications and that the hardware is acceptable for the intended usage

Adaptive Structures

autonomous structural systems which incorporate sensors, processors, and actuators to enable adaptation to changing environmental conditions, thereby enhancing safety, stability, vibration damping, acoustic noise suppression, aerodynamic performance and optimization, pointing accuracy, load redistribution, damage response, structural integrity, etc.

Allowable Load

the maximum load (force, stress, and/or strain) that can be accommodated by a structure or a component of a structural assembly without potential rupture, collapse, or detrimental deformation in a given environment

NOTE Allowable loads (forces, stresses, and/or strains) commonly correspond to the statistically-based ultimate strength, buckling strength, and yield strength.

B-Basis Allowable

the mechanical strength value above which at least 90% of the population of values is expected to fall, with a confidence level of 95%

Buckling

a failure mode in which an infinitesimal increase in the load could lead to sudden collapse or detrimental deformation of a structure

Catastrophic Failure

a failure which results in the loss of human life or mission

Collapse

the failure mode under quasi-static loads accompanied by very rapid irreversible loss of load-carrying capability

Composite Material

a combination of materials different in composition or form

NOTE 1 The constituents retain their identities in the composite.

NOTE 2 Normally the constituents can be physically identified, and there is an interface between them.

Composite Overwrapped Pressure Vessel (COPV)

a pressure vessel with a fiber-based composite system fully or partially encapsulating a liner

NOTE 1 The liner serves as a fluid permeation barrier and may or may not carry substantial pressure loads.

NOTE 2 The composite overwraps generally carry pressure and environmental loads.

Damage Tolerance

the ability of a structure or a component of a structural assembly to resist failure due to the presence of flaws, for a specified period of unrepaired usage

Design Safety Factor

a factor by which limit loads are multiplied in order to account for uncertainties and variations that cannot be analyzed or accounted for in a rational manner

NOTE Design safety factor is often referred to as design factor of safety or just factor of safety (FS).

Detrimental Deformations

all structural deformations, deflections, or displacements that prevent any portion of the structural item from performing its intended function

Development Test

a test to provide information that may be used to check the validity of analytic technique and assumed design parameters, uncover unexpected system response characteristics, evaluate design changes, determine interface compatibility, prove qualification and acceptance procedures and techniques, check manufacturing technology, or establish accept/reject criteria

Fail Safe Structure

a structural item designed with sufficient redundancy such that failure of one of its elements does not result in a catastrophic failure. In addition, the failure of the structural item must not release any potentially catastrophic free body.

Fatigue Life

the number of cycles of stress or strain of a specified character that a given structure or component of a structural assembly can sustain (without the presence of flaw) before failure of a specified nature could occur

Flaw

a local discontinuity in a structural material such as a crack, cut, scratch, void, delamination, disbond, impact damage, or other mechanical damage

Fracture Control

the application of design philosophy, analysis methods, manufacturing technology, verification methodology, quality assurance, including nondestructive evaluation (NDE) and operating procedures to prevent premature structural failure due to the propagation of flaws during fabrication, testing, transportation, handling, and service events such as launch, on-orbit operation, and return.

Fracture-Critical Part

a structural part whose failure due to the presence of a flaw would result in a catastrophic failure

Hydrogen Embrittlement

a mechanical-environmental process that results from the initial presence or absorption of excessive amounts of hydrogen in metals, usually in combination with residual or applied tensile stresses

Limit Load

the highest expected load or combination of loads that a structure or a component in a structural assembly may experience during its service life in association with the applicable operating environments

NOTE The corresponding stress is called limit stress.

Loading Case

the particular condition of load/pressure/temperature, which can occur for some structures or components of a structural assembly at some time during their service lives

Loading Spectrum

a representation of the cumulative loading levels and associated cycles anticipated for the structure or component of a structural assembly under all expected operating environments

NOTE Significant transportation, test, and handling loads are included.

Margin of Safety (MS)

$MS = [\text{Allowable Load (Yield or Ultimate)}/\text{Limit Load} \times \text{Factor of Safety (Yield or Ultimate)}] - 1$

NOTE 1 Load may mean force, stress, or strain.

NOTE 2 Definition applies to a single loading condition (mechanical, thermal, or pressure).

Maximum Expected Operating Pressure (MEOP)

the maximum pressure that pressurized hardware is expected to experience during its service life in association with its applicable operating environments

NOTE MEOP includes the effects of temperature, transient peaks, vehicle acceleration, and relief valve tolerance.

Metallic Structural Items

structural items made of metals

NOTE In this document, load bearing metallic liners of COPVs are also referred to as metallic structural items.

Moving Mechanical Assembly (MMA)

a mechanical or electromechanical device that controls the movement of one mechanical part of a vehicle relative to another part

EXAMPLES Gimbals, actuators, despin and separation mechanisms, motors, latches, clutches, springs, dampers, or bearings.

Pressure Vessel

a container designed primarily for storage of pressurized fluid that (1) contains gas or liquid with an energy level of 14,240 foot-pounds (19,310 joules) or greater, based on adiabatic expansion of a perfect gas; or (2) contains gas or liquid that will create a mishap (accident) if released; or (3) will experience a MEOP greater than 100 psi (700 kPa)

NOTE Pressurized structures, pressure components, and special pressurized equipment including batteries, heat pipes, sealed containers, and cryo-coolers are excluded.

Pressurized Structure

a structure designed to carry both internal pressure and vehicle structural loads

EXAMPLES Launch vehicle main propellant tanks, solid rocket motors, and crew cabins of manned modules.