

Standard

Space Systems – Metallic Pressure Vessels, Pressurized Structures, and Pressure Components

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American National Standard

Space Systems—Metallic Pressure Vessels, Pressurized Structures, and Pressure Components

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American Institute of Aeronautics and Astronautics

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Abstract

This standard establishes baseline requirements for the design, analysis, fabrication, test, operation, and maintenance of metallic pressure vessels, pressurized structures, batteries, heat pipes, and cryostats, dewars, sealed containers, accumulators, and pressure components such as lines, fittings, hoses, and bellows made of metals. These components are used for pressurized, hazardous, or nonhazardous liquid or gas storage in space systems including spacecraft and launch vehicles.

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Foreword

This version of S-080 was developed as an industry consensus to represent accepted practices for the design, analysis, fabrication, test, inspection, operation, and maintenance of metallic pressure vessels, pressurized structures, batteries, heat pipes, cryostats, dewars, sealed containers, accumulators, and pressure components such as lines, fittings, hoses, and bellows in space systems.

This version of S-080 was developed in collaboration with manufacturers, launch-site operators, range safety authorities, and individuals affiliated with universities and government entities.

The key elements in the revised version of this standard are as follows:

- Reformatted the requirements to align with ANSI/AIAA S-081B-2018, *Space Systems—Composite Overwrapped Pressure Vessels*
- Updated the requirements for design and verification including damage tolerance life (formerly referred to as safe life) and leak before burst
- Articulated the responsibility of the owner, manufacturer, and procuring authority
- Organized the requirements into separate sections for design, analysis, and test
- Added a design requirements verification matrix
- Added sections to identify the manufacturing, quality assurance, and operations and maintenance requirements
- Added requirements for maximum mass and required volume
- Expanded the requirements for stability and included a higher safety factor when verification is performed by analysis only
- Added requirements to address scenarios with significant combined loads
- Added an alternate set of requirements for lines and/or fittings with 1.5 inches (38 mm) outside diameter or greater
- Added requirements for quantifiable reliability and a failure modes and effects analysis
- Identified requirements associated with reuse
- Aligned sections to better identify the separate requirements for metallic pressure vessels, pressurized structures, batteries, heat pipes, cryostats, dewars, sealed containers, and pressure components such as lines, fittings, and hose made of metal
- Removed the thermal vacuum testing requirement for batteries and battery cases because they will be included in ANSI/AIAA S-136-201x, *Battery Safety Standard for Space Applications*
- Articulated requirements for data documentation
- Incorporated loading spectra into the service life

The AIAA Aerospace Pressure Vessels (APV) Committee on Standards (CoS) was initially formed in March 1996 as a working group within the AIAA Structures Committee on Standards with an emphasis on inclusion of aerospace prime companies, pressure vessel suppliers, and all applicable government agencies. Deliberations focused on adapting the standard to address commercial procurement of aerospace composite pressure vessels.

The current members of the AIAA APV CoS appreciate the valuable input from several original members, and express their gratitude to past committee members and reviewers whose contributions over many years

have resulted in an improved standard. At the time of approval of this document, members of the APV CoS were:

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Nathanael Greene, Co-Chair	NASA Johnson Space Center
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NOTE Names marked with an asterisk participated as Observer, nonvoting member.

The above consensus body approved this document in December 2017.

The AIAA Standards Executive Council (Allen Arrington, Chairperson) accepted the document for publication in March 2018.

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1 Scope

This standard establishes baseline requirements for the design, analysis, manufacturing, test, and operation of metallic pressurized hardware used for aerospace systems such as spacecraft and launch vehicles.

Requirements for metallic pressurized hardware levied from other authorities (such as Range Safety, FAA, DOT, etc.) may also be applicable. Specific applications, particularly those involving human spaceflight, may have additional requirements. There may also be additional requirements for hardware elements that are not addressed by this document, such as the presence of a propellant management device or diaphragm. The full set of these requirements should be identified before the design process begins and should be addressed through all stages of the lifecycle.

1.1 Purpose

These requirements are intended to assure the safety and enhance the success of the operation of metallic pressurized hardware in an aerospace system.

1.2 Applicability

This standard is applicable to metallic pressurized hardware. Included are metallic pressure vessels, pressurized structures, batteries, heat pipes, cryostats, dewars, sealed containers, accumulators, and pressure components such as lines, fittings, hoses, and bellows.

A companion standard, ANSI/AIAA S-081B Space Systems—Composite Overwrapped Pressure Vessels, is applicable to spaceflight composite overwrapped pressure vessels (COPVs).

1.3 Designation of Responsibilities

This section identifies the responsibilities for the key agents: owner, procuring authority, and manufacturer.

It is noted that the owner and procuring authority may be the same entity.

The procuring authority and the manufacturer may also be the same entity, in which case additional consideration should be given regarding independent oversight.

1.3.1 Owner

The owner establishes the system level requirements. The owner develops the aerospace system incorporating the metallic pressurized hardware to meet these system level requirements. The owner performs the system analysis on the aerospace system to identify the operational envelope, establishing the design requirements. The owner is responsible for determining the criticality of the aerospace system.

The owner is responsible for reviewing and approving any tailoring of requirements including the use of a document revision other than what is specified in Section 3.

The owner specifies options provided in the standard before contracting with the manufacturer. For example, the burst factor (Section 5.2.1) and design safety factor (Section 5.2.4) are established. In addition, for the conditions established in Section 5.1, there may be options for the design and verification approach (Section 6).

The owner has the responsibility for approving engineering source approved (ESA) processes and subsequent changes. The owner should solicit engineering input prior to accepting ESA process changes.

The owner may delegate any of the above authority and decision making responsibility to a procuring authority (typically an intermediate contractor or a consultant) but remains responsible for the overall system.

The owner should give special consideration before accepting (or allowing the procuring authority to accept) deviations from approved procedures and acceptance criteria.

Upon acceptance of the aerospace system, the owner is responsible for the operation of the metallic pressurized hardware. The owner should operate the metallic pressurized hardware in compliance with the Operations and Maintenance Requirements specified in Section 11.

1.3.2 Procuring Authority

The procuring authority performs on behalf of the owner those responsibilities and authorities contractually agreed between the two parties.

Typically this includes delegated authority from the owner for development of an aerospace system incorporating the metallic pressurized hardware, performance of the system analysis on the aerospace system to identify the operational envelope as specified in Section 5.1, and establishing the design requirements as specified in Section 5.2.

This standard permits options for the metallic pressurized hardware. With concurrence from the owner, the procuring authority may specify such options before contracting with the manufacturer. For example, the burst factor (Section 5.2.1) and design safety factor (Section 5.2.4) are established. In addition, for the conditions established in Section 5.1, there may be options for the design and verification approach (Section 6).

With concurrence from the owner, the procuring authority may have final responsibility for manufacturing and design decisions and may be required to review and approve all manufacturing and test procedures and results. This includes the preparation of coupons, samples, and/or test specimen components that are representative of the flight pressurized hardware for damage tolerance and LBB verification by test.

The procuring authority should give special consideration before accepting deviations from approved procedures and acceptance criteria.

1.3.3 Manufacturer

The manufacturer is responsible for the overall design and fabrication of the metallic pressurized hardware, including analysis and testing. This process involves procuring materials, constructing, testing, and certifying that the metallic pressurized hardware is in compliance with the requirements of this standard as tailored by the owner and the procuring authority. The manufacturer is also responsible for developing the documentation required throughout the design and manufacturing of the metallic pressurized hardware.

2 Tailoring

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 owner and procuring authority (as appropriate).

NOTE 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 cases, modification, and addition, or deletion of requirements in the standards. Such exceptions or modifications should be expressly delineated in applicable purchase orders, contracts, and other technical documents.

3 Applicable Documents

The following documents contain provisions which either through reference in the text constitute requirements of this standard, or which provide useful background or guidance relevant to this standard.

For dated references the specified edition applies. For undated references, the edition in effect at time of publication of this standard applies.

AFFDL-TR-79-3021	<i>USAF Damage Tolerance Design Handbook: Guidelines for the Analysis and Design of Damage Tolerant Aircraft Structures</i> , 1994
AFML-TR-68-115	<i>Aerospace Structural Metals Handbook 38th edition</i> 2004, or online <i>Aerospace Structural Metals Database</i> , CINDAS LLC 2007
ANSI/AIAA S-136	<i>Battery Safety Standard for Space Applications (in preparation)</i>
ANSI/AIAA S-081B	<i>Space Systems—Composite Overwrapped Pressure Vessels</i> , 2018
AS-9100	<i>Quality Management Systems—Requirements for Aviation, Space and Defense Organizations</i> , 2009
ASTM E647	<i>Standard Test Method for Measurement of Fatigue Crack Growth Rates</i> , 2015
ASTM E740/E740M-03 (Reapproved 2010)	<i>Standard Practice for Fracture Testing with Surface-Crack Tension Specimens</i> , 2003.
ASTM E2899-15	<i>Standard Test Method for Measurement of Initiation Toughness in Surface Cracks Under Tension and Bending</i> , 2015
DOT/FAA/AR-MMPDS-10	<i>Metallic Materials Properties Development Standardization (MMPDS)</i> , 2015
ISO 9000	<i>Quality management systems—Requirements</i> , 2015
MIL-STD-1540D	<i>Military Standard, Product Verification Requirements for Launch, Upper-Stage, and Space Vehicles</i> , January 1999 (Cancelled July 28, 2016).
NASA-SP-8007	<i>Buckling of Thin-Walled Circular Cylinders</i> , August 1968.
SMC-S-016	<i>Test Requirements for Launch, Upper-Stage and Space Vehicles</i> , 2014

4 Vocabulary

4.1 Acronyms and Abbreviated Terms

<i>a</i>	minor semi-axis of an elliptical flaw (crack)
AFFDL	Air Force Flight Dynamics Laboratory
AFML	Air Force Materials Laboratory
AIAA	American Institute of Aeronautics and Astronautics
ANSI	American National Standards Institute
<i>BF</i>	burst factor
<i>c</i>	major semi-axis of an elliptical flaw (crack)
C	Celsius

COPV	composite overwrapped pressure vessel
da/dN	fatigue crack growth rate in the “a” direction
dc/dN	fatigue crack growth rate in the “c” direction
DoT	Department of Transportation
ECF	environmental correction factor
ESA	engineering source approved (as in ESA process)
FAA	Federal Aviation Administration
FMEA	failure modes and effects analysis
F_{su}	shear ultimate strength
F_{tu}	tensile ultimate strength
F_{ty}	tensile yield strength
K	stress intensity factor
K_c	plane stress fracture toughness
K_{Ic}	plane strain fracture toughness
K_{Ie}	surface or embedded crack fracture toughness
K_{IEAC}	stress intensity factor threshold for plane strain environmentally assisted cracking
K_R	crack extension resistance
ΔK_{th}	cyclic threshold stress intensity range
LBB	leak before burst
LEFM	linear elastic fracture mechanics
MEOP	maximum expected operating pressure
MEPD	maximum external pressure differential
MIL	military
MRB	Material Review Board
MS	margin of safety
NASA	National Aeronautics and Space Administration
NDT	nondestructive testing
POD	probability of detection
QA	quality assurance
$\varepsilon-N$	strain-life
$S-N$	stress-life
STD	standard
t	pressurized hardware wall thickness

USAF United States Air Force

4.2 Terms and Definitions

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

A-basis allowable

the lower of either a statistically calculated number or the specification minimum (S-basis). The statistically calculated number indicates that at least 99% of the population of values is expected to equal or exceed the specified values, with a confidence level of 95%.

Acceptance tests

the required tests conducted by the manufacturer on a flight item to ascertain that the materials, manufacturing processes, and workmanship meet specifications and that the item is acceptable for its intended use

Allowable load

the maximum load that can be accommodated by a structure (material) without rupture, collapse, or detrimental deformation in a given environment

NOTE Allowable loads commonly correspond to the statistically based minimum ultimate strength, buckling strength, and yield strength, as applicable.

Battery

a container consisting of one or more cells in which chemical energy is converted into electricity for use as a source of power

Bellows

a corrugated single-layer or multi-layer casing, capable of performing linear, shear, and angular movements

NOTE An expansion joint may consist of both a convoluted bellows section and a mechanical linkage section, which serves as a bellows restraint. Common mechanical linkage types are braids, hinges, and gimbals. In some cases a bellows contains an internal liner or flow tube for the purpose of improving flow characteristics.

Burst factor

a multiplying factor applied to the maximum expected operating pressure (MEOP) to obtain the design burst pressure

NOTE There is an environmental correction factor (ECF) to account for the difference between the conditions at which the burst test is performed and the worst case environment as defined in Section 5.1.16.

Component

a functional unit that is viewed as an entity for the purpose of analysis, manufacturing, maintenance, or record keeping

Critical process

term usually used in industry to refer to a "special" manufacturing process such as welding, heat treating or brazing that can substantially affect material properties. A critical process may also be an engineering source approved process.

Cryostat

an apparatus for maintaining a very low temperature

Cyclic threshold stress intensity factor range

the stress intensity factor range below which flaw growth will not occur under cyclic loading conditions

Damage tolerance life

the required period of time and number of cycles pressurized hardware, containing the largest undetected

crack, flaw, or discontinuity, must survive without leak or burst in the expected service environment

Defect

one or more flaws whose aggregate size, shape, orientation, location, or properties do not meet specified acceptance criteria and are rejectable

Design burst pressure

the pressure that a pressurized hardware component will sustain without rupture in the applicable operating environment

Design safety factor

a multiplying factor applied to the limit loads and/or maximum expected operating loads/stresses when evaluating adequacy of the structural design during the analytical assessment and/or test verification

NOTE The design safety factor is used to account for build-to-build hardware variability, uncertainty in internal load paths & stress/strain levels, and uncertainty in ultimate failure modes. It provides separation between the statistical distributions that describe loads and the material properties.

Detrimental deformation

distortion, deflection, or displacement that prevents any portion of the pressurized hardware from performing its intended function or that reduces the probability of successful completion of the mission

Development test

a test that is conducted by the manufacturer in order to ascertain information used to check the validity of analytical techniques and assumed design parameters; to uncover unexpected system response characteristics; to evaluate design changes; to determine interface compatibility; to prove qualification and acceptance procedures and techniques; to establish accept/reject criteria for nondestructive tests (NDT); or any other purpose necessary to establish the validity of the design and manufacturing processes

Dewar

a double-walled flask with a vacuum between the walls, used to hold liquids at well below ambient temperature

Embrittlement

An interstitial interaction of a second element or compound, or other mechanisms, within the matrix of the material that results in a reduction in the fracture toughness of the material

NOTE Examples of elements involving interstitial interactions are hydrogen in steel and liquid metals in aluminum and titanium alloys.

Engineering source approved (ESA) process

a manufacturing process that is placed under configuration management. Changes to this process would require appropriate written authorization.

NOTE Examples of ESA processes may include investment castings and unique or critical NDT techniques.

Environmental correction factor (ECF)

a multiplying factor applied to account for the change in material properties associated with the difference between the test temperature and the operating temperature

NOTE The ECF for the proof test and the ECF for the burst test may be different.

Environments

the environmental exposures (such as humidity, temperature, vibration, acoustic, shock, and radiation levels) that the pressurized hardware is subjected to after completion of manufacture and final inspection

Fatigue

the process of progressive localized permanent structural change occurring in a material subjected to fluctuating stresses and strains, and which may culminate in cracks or complete fracture after a sufficient

number of cycles

Fatigue life

the number of cycles of applied external loads and/or pressurization that the unflawed pressurized item can sustain before a fatigue failure could occur

Flaw

a local imperfection or discontinuity in a structural material (examples include cracks, voids, delamination, etc.) that may be detectable by visual inspection or nondestructive testing and is not necessarily rejectable

Flaw (crack) aspect ratio ($a/2c$ or a/c)

the aspect ratio of a surface flaw (crack) ($a/2c$), a corner flaw (crack) (a/c), or an embedded flaw (crack) (a/c) in the wall where a is the minor semi-axis and c is the major semi-axis of the flaw (crack)

Flow Stress

the average of the yield and ultimate stresses

Fracture control

the application of design philosophy, analysis method, manufacturing technology, quality assurance, and operating procedures to prevent premature structural failure due to the propagation of cracks or crack-like flaws during fabrication, testing, transportation and handling, and service

Hazard

a real or potential condition that could lead to an unplanned event or series of events (i.e. mishap) resulting in loss of personnel capability, injury, illness, or death to personnel or the public, damage to or loss of system, equipment, or property, or damage to the environment

Hazard analysis

the determination of hazards and recommended resolutions for those conditions which may cause loss of personnel capability, injury, illness, or death to personnel or the public, damage to or loss of system, equipment, or property, or damage to the environment. The hazard analysis includes assessment, causes, controls and proven mitigations.

Hazardous application

an application in which a hazard exists (i.e., a potential risk situation that may be caused by an unsafe act or condition, such as the presence of a hazardous fluid) with the exception of the explosive energy resulting from the pressure of the contained fluid(s)

Hazardous fluid

a fluid that presents a hazard

NOTE 1 Examples include fluids with high toxicity, flammability, explosivity, and corrosivity.

NOTE 2 Asphyxiation is exempted for non-crewed applications.

Leak before burst (LBB)

a design approach in which, at MEOP, assumed flaws in the wall, should they exist in any location/orientation and grow by any mechanism, result in pressure relieving leakage rather than unstable crack growth

NOTE LBB does not apply at pressures higher than MEOP unless otherwise specified for a higher pressure, and is not a safety measure against over-pressurization or combined loads.

Limit load

the maximum expected external load or combination of loads that a pressurized hardware component may experience during its service life in the specified environments

NOTE 1 When a statistical estimate is applicable, the limit load is that load not expected to be exceeded at 99% probability with 90% confidence.