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Design and Test Requirements for Space Flight Pressurized Systems

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14. ABSTRACT

This Standard establishes the baseline requirements for the design, fabrication, assembly, installation, test, inspection, operation, and maintenance of pressure systems used in spacecraft and launch vehicles. This Standard is applicable to the procurement of pressurized hardware in space systems as a compliance document.

15. SUBJECT TERMS

Pressure systems, pressurized hardware, design requirements, test requirements, acceptance test, system test

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This Document	TR-RS-2023-00005 *Design and Test Requirements for Space Flight Pressurized Systems* • Replaces TR-RS-2015-00005 • To also be published as SSC-S-005 (2023)	5 January 2023

Foreword

This Recommended Standard by The Aerospace Corporation is an update to the 2015 version of *Design and Test Requirements for Space Flight Pressurized Systems*, TR-RS-2015-00005. The Recommended Standard has as its origin all the requirements set forth for the flight pressurized systems in Section 4, General Design Requirements, and Section 6, Pressurized Systems Requirements, of MIL-STD-1522A, *Standard General Requirements of Safe Design and Operation of Pressurized Missile and Space Systems*. Unit-level requirements from MIL-STD-1522A were taken on by ANSI/AIAA S-080, *Space Systems – Metallic Pressure Vessels, Pressurized Structures, and Pressure Components* and S-081, *Space Systems – Composite Overwrapped Pressure Vessels (COPVs)*. This latest revision clarifies requirements and removes requirements that are handled by other standards.

It is the intent that this Recommended Standard be used together with the latest revisions of ANSI/AIAA S-080, *Space Systems – Metallic Pressure Vessels, Pressurized Structures, and Pressure Components* and S-081, *Space Systems – Composite Overwrapped Pressure Vessels (COPVs)* as compliance documents for the space flight pressure hardware in space system acquisitions.

An appendix was added to show tailoring that has been accepted in past systems. That is, these tailoring examples increase the risk over the baseline approach listed in the main body, but this risk increase was deemed acceptable on specific flight programs.

Contents

1. Introduction

1.1 Scope

This Recommended Standard establishes the baseline requirements for the design, assembly, installation, test, inspection, operation, and maintenance of pressure systems used in spacecraft and launch vehicles. It deals primarily with the system-level aspects related to the integrated pressure vessel(s), pressurized structures, and corresponding pressure components within a specific pressure system, and interfaces between a pressure system and other spacecraft or launch vehicle systems. These requirements, when implemented on a specific pressure system, will assure a high level of confidence in achieving safe and reliable operation.

1.2 Application

This Recommended Standard is applicable to all pressure systems installed and operated in spacecraft, launch vehicles, and other space systems. Whereas this Recommended Standard pertains to the pressure system, the pressure vessels and/or pressurized structures and all associated pressure components that comprise the system are governed by other standards used in conjunction with this document. For example, ANSI/AIAA S-080A-2018 [1] provides requirements for metallic pressure vessels and other pressure components, ANSI/AIAA S-081B-2018 [2] provides requirements for composite overwrapped pressure vessels, AIAA S-110-2005 [3] provides requirements for pressurized structures, TR-RS-2023-00006 [4] provides requirements for solid rocket motors, and TR-RS-2023-00026 [5] provides requirements for liquid rocket engines. Other system-level requirements are contained within TR-RS-2014-00016 [6].

The requirements specified in this Recommended Standard may be tailored for specific programs with the approval of the appropriate approval authority. Tailoring of the requirements should be accompanied by a risk assessment per the process detailed in MIL-STD-882 [7] to remain compliant with that standard.

2. Applicable Documents

The following documents of the issue in effect on the date of invitation for bids or request for proposal form a part of this standard to the extent cited herein.

[1]	ANSI/AIAA S-080A-2018	*Space Systems – Metallic Pressure Vessels, Pressurized Structures, and Pressure Components*, American National Standard, American National Standards Institute and American Institute of Aeronautics and Astronautics, March 2018.
[2]	ANSI/AIAA S-081B-2018	*Space Systems – Composite Overwrapped Pressure Vessels*, American National Standard, American National Standards Institute and American Institute of Aeronautics and Astronautics, March 2018.
[3]	AIAA S-110-2005	*Space Systems – Structures, Structural Components, and Structural Assemblies*, American Institute of Aeronautics and Astronautics, 12 July 2005.
[4]	TR-RS-2023-00006	*Solid Rocket Motor Case Design and Test*, The Aerospace Corporation, El Segundo, CA, January 2023. (to be released as an update to SMC-S-006, Air Force Space Command, Space Systems Command)
[5]	TR-RS-2023-00026	*Evaluation and Test Requirements for Liquid Rocket Engines*, The Aerospace Corporation, El Segundo, CA, January 2023. (to be released as an update to SMC-S-025, Air Force Space Command, Space Systems Command)
[6]	TR-RS-2014-00016	*Test Requirements for Launch, Upper-Stage, and Space Vehicles*, The Aerospace Corporation, El Segundo, CA, 25 June 2014. (Same as SMC-S-016, Air Force Space Command, Space and Missile Systems Center Standard, 26 July 2017)
[7]	MIL-STD-882E	*System Safety*, Department of Defense Standard Practice, 11 May 2012.
[8]	DoDI 5000.02	*Operation of the Adaptive Acquisition Framework*, Department of Defense Standard Instruction, 23 January 2020, https://www.esd.whs.mil/DD/.
[9]	NESC-NPP-21-01679	*Treatment of Transient Pressure Events in Space Flight Pressurized Systems*, NASA Engineering and Safety Center Position Paper, 2 September 2021.
[10]	NESC-RP-19-01498	*Filtration of Spaceflight Propulsion and Pressurant Systems*, NASA Engineering and Safety Center Technical Assessment Report, 17 February 2022.
[11]	AFSPCMAN 91-710	*Range Safety User Requirements Manual*, Air Force Space Command Manual, Volumes 1-7.

[12] MIL-STD-202H *Test Method Standard, Electronic and Electrical Component Parts*, Department of Defense, with Change 2, 18 April 2015.

Unless otherwise indicated, copies of federal and military specifications, standards, and handbooks are available from Department of Defense Single Supply Point at http://quicksearch.dla.mil.

AIAA standards must be procured directly from the owner.

Aerospace reports (TOR and TR) are available from the Aerospace Corporate Library. Requests may be made by email to library.mailbox@aero.org, or on official letterhead and addressed to:

The Aerospace Corporate Library
Mail Stop M1-199
P.O. Box 92957
Los Angeles, CA 90009-2957

3. Vocabulary

3.1 Abbreviations and Acronyms

DAF Dynamic Amplification Factor

MEOP Maximum Expected Operating Pressure

NDI Nondestructive Inspection

NVR Non-volatile Residue

3.2 Definitions

The following definitions of significant terms are provided to ensure precision of meaning and consistency of usage. In the event of a conflict, the definitions listed here apply.

Acceptable Risk: Risk that the appropriate acceptance authority (as defined in DoDI 5000.02 [8]) is willing to accept without additional mitigation.

Acceptance Tests: The required formal tests conducted to demonstrate acceptability of an item for delivery. The tests are designed to demonstrate performance to specified requirements and to act as quality control screens to detect deficiencies of workmanship, material, and quality.

Burst Factor: A multiplying factor applied to the maximum expected operating pressure (MEOP) to obtain the design burst pressure.

Burst Pressure: The real pressure level at which rupture or unstable fracture of the pressurized hardware item occurs.

Component: A functional unit that is viewed as an entity for purposes of analysis, design, manufacturing, software coding, testing, maintenance, configuration management, or recordkeeping.

Critical Condition: The most severe environmental condition for a particular failure mode in terms of loads, pressures and temperatures, or combination thereof imposed on systems, subsystems, and components (pressurized hardware within this report) during service life.

Damage-Tolerance Life: The required period of time and number of cycles that the pressurized hardware, containing the largest undetected crack, flaw, or discontinuity, must survive without leak or burst in the expected service environment.

Design Burst Pressure: The pressure that the pressurized hardware will sustain without rupture in the applicable operating environment. It is equal to the product of the maximum expected operating pressure (MEOP) and a design ultimate (burst) factor of safety.

Design Factor of Safety: A multiplying factor used in design analysis to account for uncertainties such as mechanical tolerances, analysis limitations, and manufacturing variability. The design factor of safety is often called the design safety factor, factor of safety, or, simply, the safety factor. In general, two types of design factors of safety are specified: design yield factor of safety and design ultimate factor of safety.

Dirt Holding Capacity: The amount of contaminant a filter can hold while still meeting the specified flow rate and pressure drop requirement.

Dynamic Amplification Factor (DAF): The ratio of stress obtained in a dynamic transient analysis to that obtained by a static analysis. The factor provides a comparison between the structural dynamic stress response and the static stress response due to a pressure transient.

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.

Fittings: Components of a pressurized system utilized to connect pressurized hardware.

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.

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.

Initial Flaw: A flaw or a crack-like defect in a structural material before the application of load and/or deleterious environment.

Limit Load: The maximum expected external load or combination of loads, that pressurized hardware may experience during its service life in the specified environments.

Line(s): The tubular pressure components of a pressurized system provided as a means for transferring fluids between pressurized hardware of the system.

Maximum Expected Operating Pressure (MEOP): The MEOP is the highest pressure that pressurized hardware is expected to sustain during its service life and retain its functionality. Included are the effects of applicable operating environments, maximum ullage pressure, fluid head due to vehicle quasi-steady and dynamic accelerations, water hammer, slosh, pressure transients and oscillations, temperature, and operating variability of regulators or relief valves.

Mishap: An event or series of events resulting in unintentional death, injury, occupational illness, damage to or loss of equipment or property, or damage to the environment. The term mishap includes negative environmental impacts from planned events.

Pressure Component: A component in a pressurized system, other than a pressure vessel, battery, cryostat, dewar, heat pipe, sealed container, or pressurized structure, that is designed largely by the internal pressure. Examples are lines, fittings, gauges, valves, bellows, and hoses.

Pressure Vessel: A container designed primarily for the storage of pressurized fluids and which

1) Contains stored energy of 19307 J (14,240 ft-lb) or greater, based on adiabatic expansion of a perfect gas; or

2) Contains gas or liquid in excess of 103 kPa (15 psig), which will create a mishap (accident) if released; or

3) Will experience a MEOP greater than 700 kPa (100 psig).

Pressurized Hardware: A component that contains internal pressure. Included are pressure components, pressure vessels, and pressurized structures. This category includes batteries, heat pipes, cryostats, dewars, and sealed containers.

Pressurized Structure: A structure designed to carry both internal pressure and vehicle structural loads. A typical example is the main propellant tank of a launch vehicle.

Pressurized System: A system that consists of pressure vessels, or pressurized structures, or both, and other pressure components such as lines, fittings, valves, and bellows that are exposed to and structurally designed largely by the acting pressure. Not included are electrical or other control devices required for system operation. The term *pressurized system* is synonymous with *pressure system*. Note that in other documents such as TR-RS-2014-00016 [6], the term *system* refers to the entire vehicle and *subsystem* refers to completed assemblies like propulsion. A *propulsion subsystem* per TR-RS-2014-00016 [6] is termed a *pressurized system* within this document.

Proof Factor: A multiplying factor applied to the limit load or MEOP to obtain proof load or proof pressure.

Proof Pressure: Used to give evidence of satisfactory workmanship and material quality and/or establish maximum initial flaw sizes for damage-tolerance life (safe-life) demonstration. It is equal to the product of MEOP and a proof factor.

Qualification Test(s): The required formal contractual tests used to demonstrate that the design, manufacturing, and assembly have resulted in hardware designs conforming to specification requirements.

Safety-critical: A term applied to a condition, event, operation, process, or item whose mishap severity consequence is either Catastrophic or Critical (e.g., safety-critical function, safety-critical path, and safety-critical component).

Safety-critical item: A hardware or software item that has been determined through analysis to potentially contribute to a hazard with Catastrophic or Critical mishap potential, or that may be implemented to mitigate a hazard with Catastrophic or Critical mishap potential. See MIL-STD-882E [7] for further description.

Service Life: The service life of an item starts at the completion of fabrication and continues through all acceptance testing, handling, storage, transportation, prelaunch testing, all phases of launch, orbital operations, disposal, reentry or recovery from orbit, refurbishment, retesting, and reuse that may be required or specified.

System Safety: The application of engineering and management principles, criteria, and techniques to achieve acceptable risk within the constraints of operational effectiveness and suitability, time, and cost throughout all phases of the system lifecycle.

Transient Peak Pressure: The maximum value of a pressure wave in a system filled with liquid and associated with valve actuation, fluid system priming, fluid discharge, vibration, or similar occurrence. Such transients generally persist for only a fraction of a second and their amplitude is drastically reduced when transmitted to locations containing gaseous species and/or flexible walls.

Transient Pressure Increase: The difference between the transient peak pressure and the static pressure value (occurring before and/or after the transient wave).

Ultimate Load: The product of the limit load and the design ultimate factor of safety. It is the load that the structure must withstand without rupture or collapse in the expected operating environments.

4. General Requirements

This section presents general requirements for pressurized systems in terms of design, analysis, fabrication and process control, tests, repair, and recertification. Additional detailed system requirements are presented in Section 5. Requirements specific to system safety are presented in Section 6.

4.1 System Analysis Requirements

4.1.1 System Pressure Analysis

MEOP is used as the baseline internal pressure necessary for test verification purposes. Each pressurized hardware within the pressurized system will have a MEOP. If a selected pressurized hardware is over-designed in terms of MEOP for the particular application, MEOP should still refer to the required application and a different term or qualifier should be used in referencing the over-designed capability.

The unit requirements on MEOP in ANSI/AIAA S-080A-2018 [1] and ANSI/AIAA S-081B-2018 [2] are superseded by the following more explicit set of requirements.

[4.1.1-1] A thorough analysis shall be performed to establish the correct MEOP, leak rates, flow rates and other relevant performance parameters for all pressurized hardware within the pressurized system.

[4.1.1-2] For systems with isolated sections of the system operating at different pressures, the MEOP of pressurized hardware within each isolated section shall be determined.
Examples of isolated sections include portions of a system upstream and downstream of a pressure regulator and portions of a system isolatable by closure of a valve.

[4.1.1-3] MEOP shall include the variation of pressure with temperature during the pressurized hardware's service life.

[4.1.1-4] MEOP shall include the system pressure rise allowed due to valve back pressure relief, regulator lockup behavior, and relief valve settings to include the tolerance of each of these parameters.

[4.1.1-5] MEOP shall include the effect of vehicle acceleration.

[4.1.1-6] MEOP shall include the required fault tolerance aspects that affect maximum pressure.
For example, single-fault tolerant systems with a pressure regulator must include the increased pressure provided by the redundant regulator stage lockup condition as the primary stage failure must be "tolerated" as part of the "expected" condition.

Requirements [4.1.1-1] through [4.1.1-6] are utilized to determine the maximum static pressure value, matching a condition with either little variation or variation that occurs over longer time frames as compared to a transient pressure increase.

[4.1.1-7] Transient pressure increases incident on the pressurized hardware shall be determined using validated analytical approaches and/or test data.

Validated analytical approaches include one dimensional fluid models, computational fluid dynamic models, and simpler analytical approaches. Test can include bench tests, subscale tests, full-scale tests, *and flight tests. Determination of the transient pressure increase includes defining characteristics such as pulses or cycles, frequency, and duration that will be used in structural assessments.*

[4.1.1-8] For each pressurized hardware, MEOP shall be the addition of the maximum static pressure consistent with the values determined in [4.1.1-1] through [4.1.1-6] plus any incident transient pressure increase over that steady value as determined in [4.1.1-7] multiplied by the Dynamic Amplification Factor (DAF) for the pressurized hardware.

MEOP = (static pressure) + DAF × (transient pressure increase)

The DAF is the structural response from a transient peak pressure as compared to a static or steady application of that same pressure value. A DAF of 1.0 indicates that the structural stress response for the transient pressure is equal to the stress response for the steady application of that pressure. A DAF higher than 1.0 indicates that the stress induced by the transient is greater than what would be induced by a steady application of pressure.

The transient pressure increase incident on a pressure vessel or pressurized structure is typically of little amplitude because the fluid storage vessel is typically large in comparison to inlet geometry such that an approaching pressure wave dissipates quickly within the structure. Thus, for a pressure vessel or pressurized structure, the product of DAF × (transient pressure increase) will likely be negligible.

[4.1.1-9] The DAF of the pressurized hardware shall either:

a) be determined using structural analysis or test; or

b) be an assumed value of 1.0 for pressure vessels and pressurized structures and 2.0 for pressure components.

Test for determining DAF can include bench tests, subscale tests, full-scale tests, and flight tests. See NESC-NPP-21-01679 [9] for further guidance on determining the DAF.

[4.1.1-10] For pressure components, either:

a) the proof and burst factors against limit load shall be as specified in Table 1 of ANSI/AIAA S-080A-2018 [1]; or

b) damage tolerance life verification shall demonstrate stable crack growth and non-detrimental leakage to four times the service life with an initial flaw size defined by the nondestructive inspection evaluation to 90% of probability detection and 95% confidence, with proof and burst factors against limit load as specified below:

Proof factor and design yield factor of safety = 1.1

Burst factor and design ultimate factor of safety = 1.25

The intent of [4.1.1-10b] is to provide an alternate approach to reduce the mass penalty that may result from the transient pressure increase while remaining consistent with intended margins on structural capability. As an example, take a valve with a steady-state pressure of 200 psia, a transient pressure increase of 300 psid incident on the valve when closed, and a calculated DAF of 1.0. The MEOP, with the valve in the closed position, would be 500 psia. The proof factor from Table 1 of ANSI/AIAA S-080A-2018 [1] is 1.5× resulting in a valve-closed proof pressure test condition of 750 psia. If damage tolerance life *was verified, the valve-closed proof pressure need only be 550 psia. See Appendix B for further information on damage tolerance applicability.*

[4.1.1-11] For valves and any similar pressure component where the incident transient pressure, and thus MEOP, differs depending on the valve state (open versus closed) or a similar configuration change, verification activities shall be conducted for each valve state or configuration with the associated MEOP.

Priming surge and water hammer result in the incident transient pressure for a valve being different in the open versus the closed position. The valve in the open state is verified with the open-state MEOP (and the corresponding proof and burst) and the closed state with the closed-state MEOP.

4.1.2 System Analysis

[4.1.2-1] A detailed system functional analysis of the pressurized system shall be performed to determine that the operation, interaction, and sequencing of pressurized hardware within the pressurized system are capable of supporting all required actions.

Related system safety requirements are in Section 6.

[4.1.2-2] System analysis data shall show that:

a) The system provides the capability of maintaining pressure within MEOP in the event of interruption of any process or control sequence at any time during test or flight.

b) Redundant pressure relief devices have independent pressure escape routes during all stages of operation.

4.2 Structural Design, Material, and Fabrication Requirements

As noted in Section 1, pressurized hardware requirements are covered by ANSI/AIAA S-080A-2018 [1], ANSI/AIAA S-081B-2018 [2], and AIAA S-110-2005 [3] according to the type of pressurized hardware. The only system-level structural requirements applicable within this document are to ensure that the connections between pressurized hardware are similarly addressed.

[4.2-1] The connections between pressurized hardware of the pressurized system (e.g., welds and mechanical fittings) shall be treated as pressurized hardware and therefore subject to ANSI/AIAA S-080A-2018 [1], ANSI/AIAA S-081B-2018 [2], and AIAA S-110-2005 [3] according to the type of pressurized hardware.

4.3 Contamination Control and Cleanliness Requirements

Contamination includes solid, liquid, and gaseous material unintentionally introduced into the system.

4.3.1 Design for Contamination Control

[4.3.1-1] An analysis shall be conducted to determine the sensitivity of the system and all its pressurized hardware to contamination levels to include both particulate and non-volatile residue (NVR).

[4.3.1-2] Cleanliness requirements for the system and each pressurized hardware shall be based on the contamination analysis and applied during assembly, integration, test, and final operations.

[4.3.1-3] Filters shall be placed in the system to protect sensitive pressurized hardware including pressure regulators, valves, orifices, injectors, and sealing surfaces.

4.3.2 Filter Design Requirements

[4.3.2-1] The filter rating shall be based on the pressurized hardware's sensitivity.

[4.3.2-2] Filter dirt holding capacity shall be determined based on the following aspects:

a) The cleanliness specifications of the pressurized hardware (i.e., pressure vessels and pressure components including lines and other connections between pressurized hardware), and;

b) the filtration level of fluids used in the system, and;

c) an allocation for contamination introduced during manufacturing assembly.

NESC-RP-19-01498 [10] provides further guidance on conducting filter design and dirt capacity analyses.

4.3.3 Cleanliness Testing

[4.3.3-1] Cleanliness verification tests shall use flight or flight-representative fluids.
Gas is not an appropriate medium for verifying particle count in a liquid system.

[4.3.3-2] The minimum flow rate of fluids during unit cleanliness flushing operations shall match or exceed the maximum flow rate used across component and system-level testing and in flight operations.
Cleanliness verification samples should be taken at the highest flow rate practicable. Higher level assembly cleanliness verification should use these flow rate conditions to the maximum extent practicable.

[4.3.3-3] Cleanliness verification shall include checks for particulate and NVR.

4.3.4 Foreign Object Debris Prevention

[4.3.4-1] Clean room practices and training shall be established and followed for all areas where manufacturing, integration, and test occur.

[4.3.4-2] After cleanliness verification, unsealed components or subassemblies shall be handled, transported, and stored with positive contamination controls such as end-caps and/or double bagging.

[4.3.4-3] All tools and tooling aids used in the assembly process shall be inventoried with all tools/aids/hardware independently accounted for prior to the next level of assembly or integration.

4.4 Test Requirements

ANSI/AIAA S-080A-2018 [1] and ANSI/AIAA S-081B-2018 [2] control the internal and external qualification pressure testing conducted on all pressure vessels, pressurized structures, and pressure components to demonstrate no failure at the design burst pressure. Other environmental qualification *tests are controlled by TR-RS-2014-00016 [6] or similar. Qualification testing is not required for lines and fittings that are fabricated using common aerospace materials and manufacturing processes.*

4.4.1 Integrated System Testing

The following requirements pertain to the sequencing of tests of the pressurized system.

[4.4.1-1] All flight pressurized systems shall pass acceptance testing to include a proof pressure test, a leak test at MEOP, and functional testing in that order as well as a bonding and grounding test prior to first use.
Note that functional testing may precede proof testing within a particular system test series as long as functional testing is conducted at some time after the proof test.

[4.4.1-2] Functional tests, leak tests at MEOP, and bonding and grounding tests shall be conducted prior to the final fluid fill and pressurization to flight levels at the same facility where that fill and pressurization takes place.
Shipment to a launch processing facility for system loading requires testing at that facility. A system loaded prior to shipment to the launch facility undergoes test at the facility where loading occurs.

4.4.2 Proof-Pressure Test Requirements

[4.4.2-1] For pressurized systems with isolated sections operating at different pressures, each isolated section shall be tested to its proof pressure level.
The proof pressure level will be limited by the pressurized hardware with the lowest proof factor within that isolated section.

[4.4.2-2] Proof pressure testing shall demonstrate that the flight pressure system will sustain proof pressure without distortion, damage, leakage, or loss of functionality.

[4.4.2-3] Isolated sections of a pressurized system that include relief valves and/or burst disks shall be proof tested without the relief valves and/or burst disks.
The interface connections to the relief valves and/or burst disks will not be proof tested but should undergo NDI capable of detecting detrimental flaws.

[4.4.2-4] For connections that cannot be tested to their component proof pressure level as specified in Table 1 of ANSI/AIAA S-080A-2018 [1], damage tolerance shall demonstrate stable crack growth and non-detrimental leakage to four times the service life with an initial flaw size defined by the nondestructive inspection evaluation to 90% of probability detection and 95% confidence.

The minimum proof factor and the corresponding design burst factor for tests are controlled by ANSI/AIAA S-080A-2018 [1], ANSI/AIAA S-081B-2018 [2], and AIAA S-110-2005 [3]. The limitations imposed by other pressurized hardware within the system may lead to difficulties related to the proof pressure verification of the connections between pressurized hardware as part of the system verification. ANSI/AIAA S-080A-2018 [1] Section 5.2.3 includes requirements intended to address this aspect.

4.4.3 System Leak Test Requirements

The method used to detect and/or measure leakage is purposely left unspecified. The accuracy of the method must be sufficient to verify mission requirements. The highest accuracy test practicable should be utilized. For systems to be filled with a liquid or a hazardous fluid, a suitable leak check gas may be used.

[4.4.3-1] For systems with isolated sections operating at different pressures, each isolated section shall be at its MEOP for leak tests.

[4.4.3-2] The leak test shall either:

a) use the same fluid in the leak test as the system operating fluid, or

b) use conservative leakage flow correlations between the leak test fluid and the system operating fluid to restrict the allowed leak rate.

[4.4.3-3] All mechanical connections, gasket joints, seals, weld seams, and other items susceptible to leakage shall be tested.

[4.4.3-4] Valve seals, including redundant elements relied upon for fault tolerance that are susceptible to temperature-related leakage shall be tested at the cold and hot temperature extremes during component-level qualification and acceptance tests.

[4.4.3-5] Internal and external leak rates through valves (including fill and drain valves, thruster valves, pressure relief valves, check valves, and regulators) shall be measured and verified within specification at the pressurized system level of assembly.
Verification at temperature extremes is preferred for those seals that are susceptible to temperature-related leakage. Verification checks at higher levels of vehicle build are preferred if practicable.

[4.4.3-6] For pressure assisted seals, the leakage rate shall be verified at the minimum predicted operating pressure at the pressurized system level of assembly.
Verification checks at higher levels of vehicle build are preferred if practicable.

4.4.4 System Functional Test Requirements

[4.4.4-1] System functional tests, such as those conducted as part of Specification Performance in TR-RS-2014-00016 [6], shall include flow checks to verify component interactions and the absence of major flow obstructions.

[4.4.4-2] The open/close response of all valves shall be verified as part of system functional tests.

[4.4.4-3] For critical flow control devices such as regulators, specification performance shall be verified as part of system functional tests.

[4.4.4-4] As part of system functional tests, internally redundant elements of flow control devices (including fill and drain valves) shall be independently verified for specification performance when that redundancy is required by the fault tolerance design of the system.

[4.4.4-5] For actively controlled valves, vehicle level tests shall verify end-to-end response to commands.

4.5 Reactivation and Recertification Requirements

4.5.1 Reactivation

[4.5.1-1] A flight pressure system reactivated for use after a period in either an unknown, unprotected, or unregulated ground storage environment shall be recertified to ascertain its structural integrity, functionality, and suitability for continued service before first use.

4.5.2 Recertification

The following requirements pertain to recertification of a flight pressure system prior to return to service.

[4.5.2-1] The documentation of affected pressurized hardware or portions of the flight pressure system shall be reviewed to establish the last known condition.

[4.5.2-2] The pressure system shall be inspected and subjected to appropriate NDI.

[4.5.2-3] The pressure system shall pass all the acceptance test requirements for a new system in accordance with Section 4.4.

The following requirements pertain to required tests after limited modifications and/or repair.

[4.5.2-4] If any system element such as valves, regulators, gauges, or tubing has been disconnected or reconnected for any reason, the affected system or subsystem shall be leak tested.

[4.5.2-5] For more extensive modification or repair that may affect its ability to meet the requirements of this document or its required functions, the flight pressurized system shall meet the full recertification requirements.

5. Specific System Requirements

This section presents specific design requirements that are, effectively, corrective actions to past issues. These requirements are similar to those listed in AFSPCMAN 91-710 [11], but distinct in regard to the focus on the vehicle and mission system safety aspects which align with the vehicle owner as the appropriate approval authority rather than Range Safety at the launch site.

5.1 Design Features

Design components so that, during the assembly of parts, sufficient clearance exists to permit assembly of the components without damage to the O-rings or backup rings where they pass threaded parts or sharp corners.

5.1.1 Routing

[5.1.1-1] Where straight runs are used between two rigid connection points, provision shall be made for expansion joints, motion of the units, or similar compensation to ensure that no excessive strains are applied to the tubing and fittings.
Line bends may be used to ease stresses induced in tubing by alignment tolerance and vibration.

[5.1.1-2] Flexhoses, meaning any flexible connector type, shall be used between any two connections where relative motion can be expected to fatigue metal tubes or pipes.

[5.1.1-3] Flexhose installation shall be designed to avoid abrasive contact with adjacent structure or moving parts.

[5.1.1-4] Rigid supports shall not be used on flexhoses.

5.1.2 Test Points

[5.1.2-1] Test points shall be provided such that disassembly for test is not required.

[5.1.2-2] The test points shall be easily accessible for attachment of ground test equipment.

5.1.3 Common-Plug Test Connectors

[5.1.3-1] Common-plug test connectors for pressure and return sections shall be designed to require positive removal of the pressure connection prior to unsealing the return connections.

5.1.4 Individual Pressure Test Connectors

[5.1.4-1] Individual pressure test connectors shall be designed to positively prevent inadvertent cross-connections.

5.1.5 Threaded Parts

[5.1.5-1] All threaded parts in components shall be securely locked to resist uncoupling forces by acceptable safe design methods.
Safety wiring and self-locking nuts are examples of acceptable safe design.

[5.1.5-2] Torque for threaded parts in components shall be specified.

5.1.6 Internally Threaded Bosses

[5.1.6-1] The design of internally threaded bosses shall preclude the possibility of damage to the component or the boss threads because of screwing universal fittings to excessive depths in the bosses.

5.1.7 Retainer or Snap Rings

[5.1.7-1] Retainer or snap rings shall not be used in a pressurized system where failure of the ring would allow connection failures or blowouts caused by internal pressure.

5.2 Component Selection

In all cases, flareless tube fittings must be properly preset prior to pressure applications.

5.2.1 Connections

[5.2.1-1] System connections for incompatible propellants shall be keyed, sized, or located so that it is physically impossible to interconnect them.

[5.2.1-2] Pressure components shall be selected to ensure that misconnections or reverse installations within the subsystem are not possible.

[5.2.1-3] Color codes, labels, and/or directional arrows shall be used to identify hazards and direction of flow.

5.2.2 Actuator Pressure Rating

[5.2.2-1] Components shall be specified that are capable of actuation under pressure equal to the MEOP in the circuit in which they are installed.

5.3 Design Pressures and Loads

5.3.1 Pneumatic Pressure

[5.3.1-1] Actuation of pneumatic systems shall not be adversely affected by any back-pressure resulting from concurrent operations of other parts of the system under service conditions.

5.3.2 Torque Loads

[5.3.2-1] The mounting of components, including valves, shall be on structures having sufficient strength to withstand torque and dynamic loads.
Only lightweight components that do not require adjustment after installation may be supported by the tubing, provided that a tube clamp is installed on each tube near the component.

5.3.3 Vibration Loads

[5.3.3-1] Tubing shall be supported by clamps of a suitable design and spacing to restrain destructive vibration loads.

5.4 Electrical

5.4.1 Hazardous Atmospheres

[5.4.1-1] Electric components for use in potentially ignitable atmospheres shall be verified to be incapable of causing an explosion in the intended application.

5.4.2 Solenoid Dielectric Withstanding Voltage

The test requirements in this section pertain to pressure components with internal solenoids (e.g., valves).

[5.4.2-1] All solenoids shall safely withstand a test voltage of not less than 1500 V rms at 60 cps for 1 minute between terminals and case.
See Test Method 301 in MIL-STD-202H [12] for additional clarification of this dielectric withstanding voltage test.

[5.4.2-2] The dielectric withstanding voltage test shall occur after a maximum temperature exposure, such as thermal bake-out of the coil and potting compound, to verify no voids or cracked insulation during manufacture.

5.5 Pressure Relief

Pressure relief devices are an acceptable means of providing fault tolerance against over-pressure conditions.

5.5.1 Flow Capacity

[5.5.1-1] All pressure relief devices shall provide relief at full-flow capacity at conditions up to 110% of the MEOP of the system.

5.5.2 Sizing

[5.5.2-1] The size of pressure relief devices shall be specified to withstand maximum pressure and flow capacities of the pressure source, to prevent pressure exceeding 110% of the MEOP of the system.

5.5.3 Pump Pressure Relief

[5.5.3-1] Hydraulic systems employing power-operated pumps shall include a pressure-regulating device and an independent safety-relief valve.

5.5.4 Thermal Pressure Relief

[5.5.4-1] Thermal-expansion relief valves shall be installed as necessary to prevent system damage from thermal expansion of hydraulic fluid, as in the event of gross overheating.
Internal valve leakage is not considered an acceptable method of providing thermal relief.

5.6 Hydraulic System Components

5.6.1 Variable Response

[5.6.1-1] Shutoff valves shall not be used in hydraulic systems where the event of force balance on both inlet ports may occur, thus causing the shutoff valve to restrict flow from the outlet port.

5.6.2 Fire Resistant Fluids

[5.6.2-1] Fire resistant or flame proof hydraulic fluid shall be used where the system design can expose hydraulic fluid to potential ignition sources or where the system is adjacent to a potential fire zone and the possibility of flame propagation exists.
This requirement does not pertain to propellants, but their usage in hydraulic actuation of other mechanisms must consider protection against inadvertent ignition.

5.6.3 Accumulators

[5.6.3-1] Hydraulic systems incorporating accumulators shall be interlocked to either vent or to isolate accumulator fluid pressure when power is shut off.

5.6.4 Lock Valves

[5.6.4-1] When two or more hydraulic actuators are mechanically tied together, only one lock valve shall be used to hydraulically lock all the actuators.

[5.6.4-2] Hydraulic lock valves shall not be used for lockup periods likely to involve extreme temperature changes, unless fluid expansion and contraction effects are accounted for.

5.6.5 Cavitation

[5.6.5-1] The inlet pressure of hydraulic pumps shall be specified to prevent cavitation effects in the pump passage or outlets.

[5.6.5-2] Hydraulic systems shall have positive protections against breaking the fluid column in the suction line during standby.

6. System Safety Requirements

The following requirements are specific to system safety which is governed by MIL-STD-882E [7]. The system safety requirements are based on an approach of acceptable risk which is defined as risk that the appropriate acceptance authority is willing to accept. These requirements are similar to those listed in AFSPCMAN 91-710 [11], but distinct in regard to the focus on the vehicle and mission system safety aspects that align with the vehicle owner as the appropriate approval authority.

Acceptance of risk within the following requirements does not take precedence over the requirements listed in Sections 4 and 5. Any apparent conflicts that arise must be adjudicated by tailoring of or waivers to the prior requirements along with completion of the MIL-STD-882E [7] assessment process.

6.1 System Hazard Analysis

[6.1-1] A system hazard analysis shall be performed on all pressurized system hardware, to identify hazards to the system, personnel, and facilities.

[6.1-2] All storage, handling, transportation, prelaunch processing, launch, post-launch, reuse/refurbishment operations, and associated conditions shall be included in the analysis.

[6.1-3] A detailed system physical and functional analysis of the pressurized system shall be performed to determine if the components within the pressurized system are capable of supporting all requirements without leading to a catastrophic or critical mishap based on their operation, interaction, environment, and sequence of events.

[6.1-4] The physical and functional analysis shall identify any single malfunction, software error, or personnel error in the operation of any component that may create conditions leading to an unacceptable risk of a mishap.

[6.1-5] The physical and functional analysis shall also evaluate any secondary or subsequent occurrence, failure, component malfunction, or software errors initiated by one or more primary events that could result in a mishap.

[6.1-6] Hazards identified by the analysis that may lead to catastrophic or critical hazards shall be designated as safety-critical.

[6.1-7] Safety-critical items shall require mitigation by one or more of the following, listed in order of decreasing effectiveness:

a) Design modifications to eliminate the hazard.

b) Reduce risk through design alteration.

c) Incorporate engineered features or devices that reduce the severity or the probability of the mishap potential caused by the hazard(s). In general, engineered features actively interrupt the mishap sequence and devices reduce the risk of a mishap.

d) Provide warning devices.

e) Incorporate signage, procedures, training, and personal protective equipment.

For hazards assigned Catastrophic or Critical mishap severity categories, the use of signage, procedures, training, and PPE as the only risk reduction method should be avoided.

6.2 Redundancy

[6.2-1] System analysis data shall show that:

a) In systems where pressure regulator failure involves a safety-critical hazard, regulation is redundant and where passive redundant systems are used includes automatic switchover.

b) When the hazardous effects of safety critical failures or malfunctions are prevented through the use of redundant components or systems, all such redundant components or systems have a high probability of being operational prior to the initiation of irreversible portions of safety critical operations or events.

Appendix A. Tailoring Examples

The following sections show tailoring that has been accepted for programs when the resultant risk was accepted by the controlling authority. Being of sufficiently low risk on one program does not constitute a low risk rating for all systems.

A.1. Guidance References

[A1] GSFC-STD-1000G, *Rules for the Design, Development, Verification, and Operation of Flight Systems*, Goddard Space Flight Center, Greenbelt, MD, Revalidated 30 June 2021.

[A2] Mueller, M. J., "Lessons from the AEHF-1 Bipropellant Maneuver Anomaly with Recurring Themes," AIAA 015-3955, *51st AIAA/SAE/ASEE Joint Propulsion Conference*, Orlando, FL, 27-29 July 2015.

A.2. Section 4.1.1 System Pressure Analysis

The detailed breakdown of the elements that comprise MEOP determination is intentional to clearly show the effect of tailoring to remove any requirement. For example, there have been past flight programs that omitted the fault tolerance effect of regulators such that secondary stage operation resulted in exceedance of the MEOP value. Such an approach increases mission risk and is weighed against the cost for compliance and the likelihood of regulator primary stage failure.

Calculation of the pressure transient, [4.1.1-7], was previously assumed to be part of the MEOP determination but not separately listed as a requirement. The main purpose of this requirement is in establishing the inputs to determine the DAF in [4.1.1-9], which was also not previously included. Past programs have effectively assumed that the DAF was equal to one. It remains possible that the DAF could be determined to be 1.0 using past flight history if that flight data is sufficient to be considered as test data.

Some past flight programs have allowed proof pressure of components to be exceeded by transient peak pressure. This approach is considered inappropriate as the risk incurred can be significant. Requirements in GSFC-STD-1000G [A1] call for proof pressure to exceed transient peak pressure and allow the MEOP to be calculated without the transient pressure increase (or use of DAF). This approach does incur increased mission risk, especially if the DAF may be higher than 1.0, but has been successfully implemented in flight programs.

Example tailoring to align with GSFC-STD-1000G [A1] is shown with the following changes to [4.1.1-8], [4.1.1-9], [4.1.1-10], and [4.1.1-11].

[4.1.1-8T] For each pressurized hardware, MEOP shall be the maximum static pressure consistent with the values determined in [4.1.1-1] through [4.1.1-6], and may exclude any incident transient pressure increase over that steady value as determined in [4.1.1-7].

MEOP = (static pressure)

The above tailoring includes the fact that the amplitude of transients upon entering a pressure vessel or pressurized structure has little amplitude so that the omission of the transient pressure increase is insignificant and remains consistent with the requirements in ANSI/AIAA S-080A-2018 [1] and ANSI/AIAA S-081B-2018 [2].

[4.1.1-9T] The proof pressure of pressure components shall exceed the incident transient peak pressure (i.e., MEOP plus the pressure transient increase determined in [4.1.1-7]).

Alternatively, the tailoring could impose a margin factor, such as proof pressure "shall exceed 1.1× the calculated incident transient peak pressure."

[4.1.1-10T] For pressure components, the ratio of the design burst pressure to the proof pressure shall be greater than or equal to the ratio of the burst factor to the proof factor as specified in Table 1 of ANSI/AIAA S-080A-2018 [1].

If the proof factor was adjusted to accommodate peak transient pressures, [4.1.1-10T] can be accomplished by either raising the MEOP value or by increasing the burst factor.

[4.1.1-11T] For valves and any similar pressure component where the incident transient pressure differs depending on the valve state (open versus closed) or similar configuration change, proof and burst verification activities shall be conducted for each valve state or configuration with the associated transient pressure.

In valves where the open versus closed state may alter the incident transient value, the proof pressure verification must use the open-state proof pressure with the valve open and the closed-state proof pressure with the valve closed.

A.3. Section 4.3.4 Foreign Object Debris Prevention

Requirement [4.3.4-3] can be considered a lesson learned as several failures have occurred due to a failure to remove tools and tooling aids from systems (e.g., AIAA paper [A2]). It is common, however, for some contractors to only control these elements during specific operations and not the entire integration activity. The tailoring below has been used, albeit with increased risk incurred by the customer.

[4.3.4-3T] All tools and tooling aids used in the assembly process during contamination sensitive operations shall be inventoried with all tools/aids/hardware independently accounted for prior to the next level of assembly or integration.

A.4. Section 4.4.3 and 4.4.4 System Test Requirements

Requirement [4.4.3-4] calls for checking redundant seals at temperature limits. Requirement [4.4.4-4] calls for functionally testing redundant elements. Service valves are a common pressurized hardware with redundant seals yet leak testing (a form of functional verification) has historically only been conducted on the primary seal. Such tests do not verify redundant seal capability. In addition, these tests often omit cold and hot tests based on the premise that the primary seal is not susceptible to thermally induced leakage. While the metal-to-metal seal of most service valves is thermally insensitive, the same is not true for the redundant seals which typically rely upon O-rings. The justification for altering this requirement has been to align with heritage procurement as well as that the temperature limits on the vehicle are near ambient conditions so that the cold and hot extremes remain satisfied by ambient tests. The tailoring below has been used, albeit with increased risk incurred by the customer. This example tailoring does not address whether thermal cycle or thermal vacuum is appropriate; that aspect is left to TR-RS-2014-00016 [6] or similar.

[4.4.3-4T] Valve seals, including redundant elements relied upon for fault tolerance, that are susceptible to temperature-related leakage shall be tested at the cold and hot temperature extremes during component-level qualification and acceptance tests. The redundant seals of service valves are excluded from this requirement.

[4.4.4-4T] As part of system functional tests, internally redundant elements of flow control devices (excluding fill and drain valves) shall be independently verified for specification performance when that redundancy is required by the fault tolerance design of the system.

A.5. Section 5.4.2 Solenoid Dielectric Withstanding Voltage

Section 5.4.2 lists a requirement to check the dielectric withstanding voltage of the coil used in electromechanical valves. This type of test is also referred to as a HiPOT test (High Potential). This requirement has been misunderstood and ignored on many programs with the justification being that the operating voltage of the valve is much less than the 1500 V of the test. When properly described as a HiPOT test, however, it becomes apparent that this test voltage is no different than that used on harness wires used throughout a spacecraft. Failure to properly conduct HiPOT testing on harness wires has led to anomalies. The test should be conducted at the valve supplier after potting of the valve coil (and after the heat treatment of the potting compound). Heritage procurement approaches may lead to tailoring to a 500 V test rather than 1500 V. A 500 V test does not provide verification of dielectric withstanding such that prevention of insulation voids is reliant upon manufacturing process controls at the valve supplier. The tailoring below has been used, albeit with increased risk incurred by the customer.

[5.4.2-1T] All solenoids shall safely withstand a test voltage of not less than 500 V rms at 60 cps for 1 minute between terminals and case. See Reference 1 Test Method 301 for additional clarification of this dielectric withstanding voltage test.

Along with the above text change, requirement [5.4.2-2] is often removed as part of the tailoring to conform with current manufacturing steps.

A.6. Section 5 System Safety Requirements

Section 5 provides specific design requirements that are, effectively, corrective actions to past issues. The requirements within this section are duplicated by requirements in AFSPCMAN 91-710 [11]. If the customer chooses, the approval authority may reside solely with Range Safety, in which case the entirety of Section 5 may be deleted from the tailored document. This approach may incur mission risk as Range Safety's focus is ground operations and launch rather than the rest of the operational mission.

A.7. Section 6 System Safety Requirements

Section 6 provides requirements for System Safety verification. System Safety includes not only safety on the ground, but also flight assurance. This is a standard United States Space Force function but may not exist for every program or for every customer. The requirements within this section are satisfied by the same verification means used to satisfy similar requirements in AFSPCMAN 91-710 [11] although the focus is the entire mission (including flight, orbit, deorbit, and EOL disposal) rather than just launch site operations. If the customer chooses, the approval authority may reside solely with Range Safety in which case the entirety of Section 6 may be deleted from the tailored document.

Appendix B. Damage Tolerance Guidance

Correct classification of pressure components requires their limit load stress state to be one "that is designed largely by internal pressure," per the definition. Typically, the conformance to that definition is interpreted as MEOP supplying > 90% of the total limit load stress in the part. There are many cases, however, that result in significant external loads in the pressure component that may conflict with the definition of hardware categorization. Examples include fittings reacting to vibration, thermal loads, or manual installation of lines that impart significant loads. In such cases, the expectation is that the magnitude of stresses from the external load is quantified to determine whether the appropriate "effective" proof and burst factors are retained in those regions.

Reductions in "effective" proof and burst factors due to the presence of external loads, below those required by ANSI/AIAA S-080A-2018 [1], may require an application of damage tolerance life verification for those regions. It is fairly common to see different effective proof and burst factors at component termination points rather than mid-span due to the reaction of loads, nearby hardware effects, and the presence of fittings or welds. As such, the effective proof and burst factors tend to vary about the component, which is useful for determining regions of criticality that may require special consideration in the design process. Design changes to reduce external loads or testing with increased applied proof and burst factors to achieve the correct "effective" proof factors can mitigate the need for damage tolerance life verification. Conversely, the use of reduced factors requires damage tolerance verification.

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