INTERNATIONAL STANDARD

ISO 24638

First edition
2008-11-15

Space systems — Pressure components and pressure system integration

Systèmes spatiaux — Intégration des composants sous pression et des systèmes sous pression

Reference number
ISO 24638:2008(E)

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 24638 was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

Introduction

Space vehicles and their launch systems usually have a series of engines to use for both primary propulsion and secondary propulsion functions, such as attitude control and spin control.

Different engines have different propellant feed systems; for example, the gas-pressure feed system is typically used for liquid propellant engines, and it consists of a high-pressure gas tank, a fuel tank and an oxidizer tank, valves and a pressure regulator. All these components are referred to as pressurized hardware.

Due to their specific usage, the liquid propellant tanks and the high-pressure gas bottles are often referred to as pressure vessels, while valves, regulators and feed lines are usually called pressure components.

ISO 14623 sets forth the standard requirements for pressure vessels in order to achieve safe operation and mission success. However, the requirements for pressure components are not covered in ISO 14623. Furthermore, the standard requirements for pressure system integration are lacking.

Significant work has been done in the area of design, analysis and testing of pressure components for use in space systems. This International Standard establishes the preferred methods for these techniques and sets forth the requirements for assembly, installation, test, inspection, operation and maintenance of the pressure systems in spacecraft and launch vehicles.

Space systems — Pressure components and pressure system integration

1 Scope

This International Standard establishes the baseline requirements for the design, fabrication and testing of space flight pressure components. It also establishes the requirements for assembly, installation, test, inspection, operation and maintenance of the pressure systems in spacecraft and launch vehicles. These requirements, when implemented on a particular space system, ensure a high level of confidence in achieving safe and reliable operation.

This International Standard applies to all pressure components other than pressure vessels and pressurized structures in a pressure system. It covers lines, fittings, valves, bellows, hoses and other appropriate components that are integrated to form a pressure system.

The requirements for pressure vessels and pressurized structures are set forth in ISO 14623.

This International Standard does not apply to engine components.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 14623, *Space systems — Pressure vessels and pressurized structures — Design and operation*

ISO 21347, *Space systems — Fracture and damage control*

3 Terms and definitions

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

3.1
A-basis allowable
mechanical strength value above which at least 99 % of the population of values is expected to fall, with a confidence level of 95 %

NOTE See also **B-basis allowable** (3.3).

3.2
applied load
applied stress
actual load (stress) imposed on the hardware in the service environment

3.3
B-basis allowable
mechanical strength value above which at least 90 % of the population of values is expected to fall, with a confidence level of 95 %

NOTE See also **A-basis allowable** (3.1).

3.4
component
functional unit that is viewed as an entity for the purpose of analysis, manufacturing, maintenance, or record keeping

3.5
critical condition
most severe environmental condition in terms of loads, pressures and temperatures, or combinations thereof, imposed on systems, subsystems, structures and components during service life

3.6
damage tolerance
ability of a material or structure to resist failure due to the presence of flaws, cracks, delaminations, impact damage or other mechanical damage for a specified period of unrepaired usage

3.7
damage tolerance analysis
safe-life analysis
fracture mechanics-based analysis that predicts the flaw growth behaviour of a flawed hardware item which is under service load spectrum with a pre-specified scatter factor

3.8
design burst pressure
burst pressure
ultimate pressure
differential pressure that pressurized hardware needs to withstand without burst in the applicable operational environment

NOTE Design burst pressure is equal to the product of the maximum expected operating pressure or maximum design pressure and a design burst factor.

3.9
design safety factor
design factor of safety
factor of safety
multiplying factor to be applied to limit loads and/or maximum expected operating pressure (or maximum design pressure)

3.10
detrimental deformation
structural deformation, deflection or displacement that prevents any portion of the structure or other system from performing its intended function

3.11
fittings
pressure components of a pressurized system used to connect lines, other pressure components and/or pressure vessels within the system

3.12
hazard
existing or potential condition that can result in an accident

3.13
hydrogen embrittlement
mechanical-environmental failure 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

3.14
limit load
highest predicted load or combination of loads that a structure can experience during its service life, in association with the applicable operating environments

NOTE The corresponding stress is called “limit stress”.

3.15
lines
tubular pressure components of a pressurized system provided as a means for transferring fluids between components of the system

NOTE Flexhoses are included.

3.16
loading spectrum
representation of the cumulative loading anticipated for the structure under all expected operating environments

NOTE Significant transportation and handling loads are included.

3.17
maximum allowed working pressure
MAWP
maximum differential pressure of a component designed to withstand safety and continue to operate normally when installed in any pressure system

3.18
maximum design pressure
MDP
highest differential pressure defined by maximum relief pressure, maximum regulator pressure and/or maximum temperature, including transient pressures, at which a pressurized hardware item retains two-fault tolerance without failure

3.19
maximum expected operating pressure
MEOP
highest differential pressure that a pressurized hardware item is expected to experience during its service life and yet retain its functionality, in association with its applicable operating environments

NOTE In this International Standard, the use of the term “maximum expected operating pressure (MEOP)” also signifies “maximum design pressure (MDP)”, “maximum operating pressure (MOP)” or “maximum allowed working pressure (MAWP)”, as appropriate, for a specific application or programme.

3.20
maximum operating pressure
MOP
maximum differential pressure at which the component or the pressure system actually operates in an application

NOTE MOP is synonymous with MEOP.

3.21
pressure component
component in a pressure system, other than a pressure vessel, or a pressurized structure that is designed largely by the internal pressure

EXAMPLE Lines, fittings, pressure gauges, valves, bellows and hoses.

3.22
pressure vessel
container designed primarily for the storage of pressurized fluids, which either contains gas/liquid with high energy level, or contains gas/liquid that will create a mishap (accident) if released, or contains gas/liquid with high pressure level

NOTE 1 This definition excludes pressurized structures and pressure components.

NOTE 2 Energy and pressure levels are defined by each project and approved by the procuring authority (customer). If appropriate values are not defined by the project, the following levels are used:

— stored energy is at least 19 310 J, based on adiabatic expansion of perfect gas;

— MEOP is at least 0,69 MPa.

3.23
pressurized structure
structure designed to carry both internal pressure and vehicle structural loads

EXAMPLE Launch vehicle main propellant tank, crew cabins, manned modules.

3.24
pressure system
system that consists of pressure vessels or pressurized structures, or both, and other pressure components such as lines, fittings, and valves, which are exposed to, and structurally designed largely by, the acting pressure

NOTE The term “pressure system” does not include electrical or other control devices required for system operations.

3.25
proof factor
multiplying factor applied to the limit load or MEOP (or MAWP, MDP and MOP) to obtain proof load or proof pressure for use in the acceptance testing

3.26
proof pressure
product of MEOP (or MAWP, MDP and MOP) and a proof factor

NOTE The proof pressure is used to provide evidence of satisfactory workmanship and material quality and/or to establish maximum initial flaw sizes for damage tolerance life (safe-life) demonstration

3.27
scatter factor
multiplying factor to be applied to the number of load/pressure cycles, for the purpose of covering the scatters that potentially exist in the material’s fatigue or crack growth data

3.28
service life
period of time (or cycles) that starts with the manufacturing of the pressurized hardware and continues through all acceptance testing, handling, storage, transportation, launch operations, orbital operations, refurbishment, re-testing, re-entry or recovery from orbit, and reuse that can be required or specified for the item

4 Abbreviated terms

For the purposes of this document, the following abbreviated terms apply.

COPV	composite overwrapped pressure vessel
MAWP	maximum allowed working pressure
MDP	maximum design pressure
MEOP	maximum expected operating pressure
MOP	maximum operating pressure
NDI	non-destructive inspection
QA	quality assurance

5 General requirements

5.1 General

This clause presents the general requirements for pressure components in a pressure system regarding

- design and analysis,
- material selection and characterization,
- fabrication and process control,
- quality assurance (QA),
- operation and maintenance (including repair and refurbishment), and
- storage.

The general pressure system requirements are presented in Clause 6. The integration requirements for specific pressure systems are presented in Clause 7.

5.2 Design requirements

5.2.1 Loads, pressures and environments

The anticipated load-pressure-temperature history and other associated environments throughout the service life of the pressure system shall be determined in accordance with specified mission requirements. As a minimum, the following factors and their statistical variations shall be considered appropriate:

a) environmentally induced loads and pressures;

b) environments acting simultaneously with these loads and pressures with their proper relationships;

c) frequency of application of these loads, pressures and environments, and their levels and durations.

These data shall be used to define the design load/environment spectra, which shall be used for both design analysis and testing. The design spectra shall be revised as the structural design develops and the loads analysis matures.

5.2.2 Strength

Pressure components and their interconnections in a pressure system shall possess sufficient strength to withstand limit loads and MEOP in the expected operating environments throughout the service life without incurring detrimental deformation. The pressure components shall sustain proof pressure without leaking or incurring detrimental deformation. They shall also withstand ultimate loads and design burst pressure in the expected operating environments without rupturing or collapsing.

The minimum proof test factor for pressure components shall be 1,5. The minimum design burst factor varies depending on the type of pressure component. Table A.1 presents recommended minimum proof test factors and design burst factors for various pressure components.

A pressure system shall possess sufficient strength at the component interfaces, attachments, tie-downs and other critical points. The pressure system shall sustain proof pressure without experiencing leakage and incurring detrimental deformation.

5.2.3 Stiffness

The mounting and arrangement of all components in a pressure system shall provide adequate stiffness not to generate destructive vibration, shock and acceleration, and to prevent excess stresses at the interfaces between components and at mounting brackets when subjected to limit loads, MEOP and deflections of the supporting structures in the expected operating environments. Connections between adjacent components shall be designed to prevent excessive stresses at their interfaces from combined effects of limit loads, MEOP and deflections of the supporting structures in the expected operating environments.

5.2.4 Thermal effects

Thermal effects, including heating and cooling rates, temperatures, thermal gradients, thermal stresses and deformations, and changes with temperature of the physical and mechanical properties of the material of construction, shall be factored into the design of the flight pressure system. Thermal effects shall be based on temperature extremes that simulate those predicted for the operating environment, plus a predefined design margin. The design margin shall be based on national industry heritage, including experience in thermal effects that are important to a specific pressure component.

5.2.5 Stress analysis

A detailed stress analysis shall be performed on the pressure components and assembled and installed pressure system to demonstrate acceptable stress levels and deflections at the interfaces between components, at component attachments and tie-downs to support structures, and at other critical points in the system. The effects of flexure of lines, as well as supporting structures being acted on by the flight loads, pressures and temperature and thermal gradients, shall be accounted for in the analysis. The stress analysis shall also take into account the ground loads.

5.2.6 Fatigue analysis/damage tolerance (safe-life) analysis

In addition to the stress analysis, conventional fatigue-life analysis shall be performed, as appropriate, on the pressure component and the assembly. Nominal (average) values of fatigue-life (S-N) data shall be used in the analysis. A scatter factor of four shall be used on service life as specified in ISO 14623. In some cases, fatigue analysis shall be replaced by damage tolerance (safe-life) analysis in accordance with ISO 21347.

5.3 Material requirements

5.3.1 Metallic materials

5.3.1.1 General

Metallic materials used in the assembly and installation of pressurized system components shall be selected, evaluated and characterized to ensure all system requirements are met.

5.3.1.2 Metallic material selection

Metallic materials shall be selected on the basis of proven environmental compatibility, material strength, and fatigue characteristics. Unless otherwise specified, A-basis allowable materials shall be used in any application where failure of a single load path would result in loss of structural integrity to any part of the pressurized system. For applications where failure of a redundant load path would result in a safe redistribution of applied loads to other load-carrying members, B-basis allowable materials may be used.

5.3.1.3 Metallic material evaluation

The selected metallic materials shall be evaluated with respect to material processing, fabrication methods, manufacturing operations, refurbishment procedures and processes, and other factors that affect the resulting strength and fracture properties of the material in the fabricated as well as the refurbished configurations.

The evaluation shall ascertain whether the mechanical properties, strengths, and fatigue properties used in design and analyses will be realized in the actual hardware and verify that these properties are compatible with the fluid contents and the expected operating environments. Materials that are susceptible to stress-corrosion cracking or hydrogen embrittlement shall be evaluated by performing sustained load fracture tests when applicable data are not available.

5.3.1.4 Metallic material characterization

The allowable mechanical and fatigue properties of all selected metallic materials shall be obtained from reliable sources approved by the procuring authority. Where material properties are not available, they shall be determined by test methods approved by the procuring authority.

5.3.2 Non-metallic material requirements

Non-metallic materials used in the pressure components and the assembly and installation of flight pressure components shall be selected, evaluated and characterized to ensure their suitability for the intended application.

5.4 Fabrication and process requirements

Proven processes and procedures for fabrication and repair shall be used to preclude damage or material degradation during material processing, manufacturing operations and refurbishment. Special attention shall be given to ascertaining whether the melting, welding, bonding, forming, joining, machining, drilling, grinding, repair operations and other processes applied to joining system components and hardware and attaching mounting hardware are within the state of the art and have been used on similar hardware.

The mechanical and physical properties of the parent materials, weld joints and heat-affected zones shall be within established design limits after exposure to the intended fabrication processes. The machining, forming, joining, welding, dimensional stability during thermal treatments and through-thickness hardening characteristics of the material shall be compatible with the fabrication processes encountered.

Special precautions shall be exercised throughout the manufacturing operations to guard against processing damage or other structural degradation.

Bonding, clamping and joining at the interfaces and mountings of the flight pressure systems shall be controlled to ensure that all requirements are met.

5.5 Contamination control and cleanliness requirements

5.5.1 General contamination control requirements

Required levels of contamination control shall be established by the actual cleanliness needs and the nature of the flight pressure system and its components. Contamination includes solid, liquid and gaseous material unintentionally introduced into the system. General contamination control requirements are as follows:

a) protection from contaminants shall be provided by adequate filtration, sealed modules, clean fluids and a clean environment during assembly, storage, installation and use;

b) the design shall allow for verification that the lines and other components are clean after flushing and purging; and

c) the design shall ensure that contaminants and waste fluids can be flushed and purged.

5.5.2 Design considerations

The following considerations shall be factored into the design of flight pressure systems to minimize and effectively control contamination:

a) contamination shall be minimized from entering or developing within the system;

b) the system shall be designed to include provisions to detect contamination;

c) the system shall be designed to include provisions for removal of contamination and provisions for initial purge with fluid or gas that will not degrade future system performance;

d) the system shall be designed to be tolerant of contamination;

e) unless otherwise specified, all pressurizing fluids entering the system shall be filtered through a 10 µm filter, or finer, before entering the system;

f) all pressure systems shall have fluid filters in the system, designed and located to reduce the flow of contaminant particles to a safe minimum;

g) all of the circulating fluid in the system shall be filtered downstream from the pressure pump, or immediately upstream from safety critical actuators;

h) entrance of contamination at test points or vents shall be minimized by downstream filters;

i) the bypass fluid or case drain flow on variable displacement pumps shall be filtered; and

j) when the clogging of small orifices could cause a hazardous malfunction or failure of the system, each orifice shall be protected by a filter element (including servo valves) designed to prevent clogging.

5.6 Quality assurance programme requirements

5.6.1 General

A quality assurance (QA) programme shall be established to ensure that the product and engineering requirements, drawings, material specifications, process specifications, workmanship standards, design review records, failure mode analysis, non-destructive inspection (NDI) and acceptance tests are effectively used, such that the completed flight pressure system meets its specified requirements.

The programme shall ensure

- that materials, parts, subassemblies, assemblies and all completed and refurbished hardware conform to applicable drawings and process specifications,
- that no damage or degradation has occurred during material processing, fabrication, inspection, acceptance tests, shipping, storage, operational use and refurbishment, and
- that defects which could cause failure are detected, evaluated and corrected.

5.6.2 QA programme inspection plan requirements

An inspection master plan shall be established prior to the start of system assembly and installation. The plan shall specify appropriate inspection points and inspection techniques for use throughout the programme, beginning with material procurement and continuing through fabrication, assembly, acceptance testing, operation and refurbishment, as appropriate. In establishing inspection points and inspection techniques, consideration shall be given to the material characteristics, fabrication processes, design concepts and structural configuration. Acceptance and rejection criteria shall be established as part of the plan for each phase of inspection and for each type of inspection.

5.6.3 QA inspection technique requirements

Inspections shall include both visual inspection with appropriate magnification and NDI, as necessary.

5.6.4 QA inspection data requirements

As a minimum, inspection data shall be dealt with as follows:

a) inspection data, in the form of flaw histories, shall be maintained throughout the life of the flight pressure system;

b) these data shall be reviewed and assessed periodically to evaluate trends and anomalies associated with the inspection procedures, equipment, personnel, material characteristics, fabrication processes, design concept and structural configuration; and

c) the result of this assessment shall form the basis of any required corrective action.

5.6.5 Acceptance test requirements

5.6.5.1 General

Prior to first use, all newly assembled flight pressurized systems shall pass, in the following order,

- a proof pressure test,
- a leak test,
- a grounding test, and
- a functional test.

This test sequence shall be repeated after the system's arrival at the launch processing facility. The system-level proof pressure tests can be excluded when there is sufficient successful experience and all the components have been proof-tested at the component level.

5.6.5.2 Proof pressure test requirements

The flight pressure system shall be tested at the system-level proof pressure prior to first use. For systems with zones operating at different pressures, each zone shall be tested to its proof pressure level. Proof pressure testing shall demonstrate whether the flight pressure system will sustain proof pressure without distortion, damage, leakage or loss of functionality. The system-level proof pressure tests can be excluded when there is sufficient successful experience and all the components have been proof-tested at the component level. The exclusion of system-level proof pressure tests shall be approved by the procuring authority.

5.6.5.3 Leak test requirements

The flight pressure system shall be leak-tested at the system MEOP prior to first use. For systems with zones operating at different pressures, each zone shall be at its MEOP for the leak test. The gas used during the leak test shall be the same as the system operating fluid to the extent possible. Gas with higher permeability and reliable leakage detection is allowed as the replacement. For the systems or zones intended to be filled with a liquid, a suitable leak check gas shall be used. For systems intended to operate with hazardous fluids, a non-hazardous gas may be substituted. All mechanical connections, gasketed joints, seals, weld seams and other items susceptible to leakage shall be tested. The leak rates through fill and drain valves, thruster valves and pressure relief valves shall be measured and verified within specification. Any method demonstrated capable of detecting and/or measuring leakage is acceptable.

5.7 Qualification test requirements

Internal/external pressure testing shall be conducted on all pressure components to demonstrate no failure at the design burst pressure. Annex A presents recommended minimum design burst factors for various pressure components.

5.8 Operation and maintenance requirements

5.8.1 Operating procedure

Operating procedures shall be established for the pressurized system. The procedures shall be compatible with the safety requirements and personnel control requirements at the facility where the operations are conducted. Step-by-step directions shall be written with sufficient detail to allow a qualified technician or mechanic to accomplish the operations. Schematics that identify the location and pressure limits of all components and their interconnections into a system shall be included in the procedure, or shall be available at the time it is running. Prior to initiating or performing a procedure involving hazardous operations with flight pressure systems, practice runs shall be conducted on non-pressurized systems until the operating procedures are well rehearsed. Initial tests shall then be conducted at pressure levels not in excess of 50 % of the normal operating pressures until operating characteristics can be established and stabilized. Only qualified and trained personnel shall be assigned to work on, or with, high-pressure systems. Warning signs identifying the hazards shall be posted at the operations facility prior to pressurization.

5.8.2 Safe operating limits

Safe operating limits shall be established based on the pressure capabilities of all components and the effects of assembly into a completed system. For flight pressure systems with several zones operating at different pressure levels, safe operating levels shall be established for each zone. The safe operating limits shall be summarized in a format that will provide rapid visibility of the important structural characteristics and capability of the flight pressure system.

5.8.3 Inspection and maintenance

The results of the stress analysis (see 5.2.5) and the fatigue life or damage tolerance life (safe-life) analysis (see 5.2.6) shall be used in conjunction with the appropriate results from the structural development and qualification tests to develop a quantitative approach to inspection and repair. The allowable damage limits for each component of the flight pressure system shall be used to establish the required inspection interval and repair schedule in order to maintain the hardware to the requirements of this International Standard. NDI methods and inspection procedures to reliably detect defects and determine flaw size under the condition of use shall be developed for use in the field and depot levels, as appropriate. Procedures shall be established for recording, tracking and analysing operational data as they are accumulated in order to identify critical areas requiring corrective actions. Analyses shall include prediction of remaining life and reassessment of required inspection intervals.

5.8.4 Repair and refurbishment

When inspections reveal structural damage or defects exceeding the permissible levels, the damaged hardware shall be repaired, refurbished or replaced, as appropriate. All repaired or refurbished flight pressure systems shall be recertified in accordance with 5.8.8 after each repair and refurbishment, by means of the applicable acceptance test procedure for new hardware, in order to ensure their structural integrity and to establish their suitability for continued service.

5.8.5 Storage

A flight pressure system put into storage shall be protected against exposure to environments that could cause corrosion or other forms of material degradation. It shall be protected against mechanical degradation resulting from scratches, dents or accidental dropping of the hardware. Induced stresses caused by storage fixture constraints shall be minimized by suitable storage fixture design. In the event that storage requirements are violated, recertification specified in 5.8.8 shall be required prior to return to use.

5.8.6 Documentation

Inspection, maintenance and operation records shall be kept and maintained throughout the life of the flight pressure system. As a minimum, the records shall contain the following information:

a) temperature, pressurization history and pressurizing fluid for both tests and operations;

b) number of pressure cycles experienced, as well as number of pressure cycles allowed in safe-life analysis;

c) results of any inspection conducted, including inspector, inspection dates, inspection techniques employed, location and character of defects, and defect origin and cause; this shall include inspection made during fabrication;

d) storage condition;

e) maintenance and corrective actions performed from manufacturing to operational use, including refurbishment;

f) sketches and photographs to show areas of structural damage and extent of repairs;

g) acceptance and recertification tests performed, including test conditions and results; and

h) analyses supporting the repair or modification that may influence future-use capability.

5.8.7 Reactivation

A flight pressure system reactivated for use after a period in an unknown, unprotected or unregulated storage environment shall be recertified according to 5.8.8 in order to ascertain its structural integrity, functionality and suitability for continued service before reuse.

5.8.8 Recertification

5.8.8.1 Requirements

Any flight pressure system requiring recertification prior to return to service shall meet the following requirements:

a) the documentation of affected components or portions of the flight pressure system shall be reviewed to establish the last known condition;

b) the pressure system shall be inspected and subjected to appropriate NDI to detect any previously unknown flaws;

c) the pressure system shall pass all the acceptance test requirements for new systems in accordance with 5.6.5.

5.8.8.2 Test after limited modification and repair

If any system elements, such as valves, regulators, gauges or tubing, have been disconnected or reconnected for any reason, the affected system or subsystem shall be leak-tested in accordance with 5.6.5.3 as a minimum. For more extensive modifications or repairs that may affect its ability to meet the requirements of this International Standard or its required functions, the flight pressure system shall meet the full recertification requirements in accordance with 5.8.8.

6 General pressurized-system requirements

6.1 System analysis requirements

6.1.1 System pressure analysis

A thorough analysis of the pressure system shall be performed to establish the correct MEOP, leak rates, etc. for each pressure component. The effects of the operating parameters of each component on the MEOP shall be determined. When applicable, pressure regular lock-up characteristics, valve actuation and water hammer shall be considered for the entire service life of the pressure system.

NOTE Throughout this International Standard, limit load and MEOP are used as the baseline load and pressure. The terms MAWP and MDP are used when required to replace MEOP in a specific application.

6.1.2 System functional analysis

A detailed system functional analysis shall be performed to determine whether the operation, interaction and sequencing of components within the pressure system

— are capable of supporting all required actions, and

— lead to damage to flight hardware or ground support equipment.

The analysis shall identify all possible hardware malfunctions, software errors and personnel errors in the operation of any component that may create conditions leading to an unacceptable risk to operating personnel or equipment. The analysis shall evaluate any secondary or subsequent occurrence, failure, component malfunction or software errors initiated by a primary failure, which could result in an unacceptable risk to operating personnel or equipment.

The analysis shall also show that:

a) all pressures are maintained at safe levels in the event of a process or control sequence being interrupted at any time during test or countdown;

b) redundant pressure relief devices have mutually independent pressure escape routes during all stages of operation;

c) 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 shall be operational prior to the initiation of irreversible portions of safety-critical operations or events.

6.1.3 System hazard analysis

A system hazard analysis shall be performed on all hazardous pressure system components to identify hazards to personnel and facilities. All prelaunch and launch operations and conditions shall be included in the analysis. The results of the system functional analysis shall be used in the system hazard analysis to ensure that all operations and configurations are considered in the system hazard analysis.

Hazards identified by the analysis shall be designated safety-critical and shall be mitigated by one or more of the following methods:

a) design modifications to eliminate the hazard;

b) operating restrictions to minimize personnel exposure during hazardous periods;

c) specific hazard identification and procedural restrictions to avoid hazardous configurations; or

d) special safety supervision during hazardous operations and systems configurations.

6.2 Design features

6.2.1 Assembly

Components shall be designed so there is enough clearance to permit assembly of the components without damage to the O-rings or backup rings where they pass threaded parts or sharp corners.

6.2.2 Routing

Straight tubing and piping runs between two rigid connection points shall be avoided. Where such straight runs are necessary, provision shall be made for expansion joints, motion of the units or similar compensation in order to ensure that no excessive strains are applied to the tubing and fittings. Line bends shall be used to ease stresses induced in tubing by alignment tolerance and vibration.

6.2.3 Separation

Redundant pressure components and systems shall be physically separated for maximum advantage in case of damage or fire.

6.2.4 Shielding

Pressurized systems shall be shielded from other systems, when required, to minimize all hazards caused by proximity to combustible gases, heat sources, electrical equipment, etc. Any failure in any such adjacent system shall not result in combustion or explosion of pressure fluids or components. Lines, drains and vents shall be shielded or separated from other high-energy systems, such as heat, high voltage, combustible gases and chemicals. Drain and vent lines shall not be connected to any other lines in any way that could expose hazardous substances to the components being drained or vented. Pressure fluid reservoirs shall be shielded or isolated from combustion apparati and their heat sources.

6.2.5 Grounding

Lines and other components in a hydraulic system shall be electrically grounded to metallic structures.

6.2.6 Handling

Fixtures for safe handling and hoisting with coordinated attachment points in the system structure shall be provided.

6.2.7 Special tools

Safety-critical pressurized systems shall be designed so that special tools are not required for removal and replacement of components, unless it can be shown that the use of special tools is unavoidable.

6.2.8 Test points

Test points, when required, shall be provided so that disassembly for test is not needed. The test points shall be easily accessible for attachment of ground test equipment.

6.2.9 Common-plug test connectors

Common-plug test connectors for pressure and return sections shall be designed to have positive indication of the removal of the pressure connection prior to unsealing the return connections.

6.2.10 Individual test connectors

Individual test connectors for pressure and return sections shall be designed to prevent inadvertent cross-connections.

6.2.11 Threaded parts

All threaded parts in safety-critical 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. Torques for threaded parts in safety-critical components shall be specified.

6.2.12 Friction-type locking devices

Friction-type locking devices shall be avoided in safety-critical applications. Star washers and jam nuts shall not be used as locking devices.

6.2.13 Internally threaded bosses

The design of internally threaded bosses shall preclude the possibility of damage to the component or the boss threads caused by screwing universal fittings to excessive depths in the bosses.

6.2.14 Retainer or snap rings

Retainer or snap rings shall not be used in pressurized systems where failure of the ring would allow connection failures or blowouts caused by internal pressure.

6.2.15 Snubbers

Snubbers shall be used with all bourdon-type pressure transmitters, pressure switches and pressure gauges, except air pressure gauges.

6.3 Component selection

6.3.1 Connections

Pressure components shall be selected to ensure that hazardous disconnections or reverse installations within the subsystem are not possible. Colour codes, labels and directional arrows are not acceptable as the primary means for preventing incorrect installation.

6.3.2 Fluid temperature

The maximum fluid temperature shall be estimated early in design as part of the data for selection of safety-critical components, such as system fluid, pressurizing gas, oil coolers and gaskets.

6.3.3 Actuator pressure rating

It shall be specified that components are capable of safe actuation under a pressure equal to the maximum relief valve setting in the circuit in which they are installed.

6.3.4 Pressure rating

Pumps, valves/regulators, hoses and all such prefabricated components of a pressure system shall have proven load/pressure ratings equal to, or higher than, the limit load, MEOP, and rated service life of the system.

6.3.5 Pump selection

Appropriate national standards shall be applied in evaluating safety in pump selection.

6.3.6 Fracture and leakage

Where leakage or fracture is hazardous to personnel or critical equipment, design shall ensure that failure occurs at the outlet threads of valves before the body or the valve or the inlet threads fail under pressure.

6.3.7 Oxygen system components

Valves and other pressure components for oxygen systems of at least 20,7 MPa and which are slow-opening and slow-closing types shall be used to minimize the potential for ignition of contaminants. Such systems shall also require build-up of static electrical charges.

6.3.8 Pressure regulators

Pressure regulators destined to operate in the centre 50 % of their total pressure range shall be selected to avoid creep and inaccuracies at either end of the full operating range.

6.3.9 Manual valves and regulators

Manually operated valves and regulators shall be designed so that overtorque of the valve stem or regulator adjustment cannot damage soft seats to the extent that failure of the seat will result. Valve designs that use uncontained seats are not acceptable.

6.4 Design pressures

6.4.1 Overpressure or underpressure

Warning devices to indicate hazardous overpressure or underpressure to operating personnel shall be specified. These devices shall actuate at predetermined pressure levels designed to allow time for corrective action.

6.4.2 Back-pressure

Safety-critical actuation of pneumatic systems shall not be adversely affected by any back pressure resulting from concurrent operations of any other parts of the system under any set of conditions.

6.4.3 Pressure isolation

Pressure components that can be isolated and contain residual pressure shall be equipped with gauge reading and bleed valves for pressure safety checks. Bleed valves shall be directed away from operating personnel. Fittings or caps for bleeding pressure are not acceptable.

6.4.4 Gas/fluid separation

Pressurized reservoirs which are designed for gas/fluid separation with provision to entrap gas that may be hazardous to the system or safety-critical actuation and prevent its recirculation in the system shall be specified. This shall include the posting of instructions adjacent to the filling point for proper bleeding when servicing.

6.4.5 Compressed-gas bleeding

Compressed-gas emergency systems shall be bled directly to the atmosphere, away from the vicinity of personnel, rather than to reservoir.

6.5 Mechanical-environment design

6.5.1 Acceleration and shock loads

All lines and other components shall be installed to withstand all expected acceleration and shock loads. Shock isolation mounts may be used, if necessary, to eliminate destructive vibration and interference collision.

6.5.2 Torque loads

Components, including valves, shall be mounted 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 other component.

6.5.3 Vibration loads

Tubing shall be supported by cushioned steel tube clamps or by multiblock-type clamps that are suitably spaced to restrain destructive vibration loads.

6.6 Controls

6.6.1 Interlocks

Interlocks shall be used wherever necessary to prevent a hazardous sequence of operations and provide fail-safe capability at all times.

6.6.2 Multiple safety-critical functions

Pressure systems that combine several safety-critical functions shall have sufficient controls for isolating failed functions so that remaining functions can be operated safely.

6.6.3 Critical flows and pressures

Pressure systems shall have pressure-indicating devices to show safe upper and lower limits of system pressure. The pressure indicators shall be readily visible to the operating crew.

6.7 Protection

Unless otherwise specified, all systems for pressure above 3,45 MPa in all areas where damage can occur during servicing or other operational hazards shall be protected. Hazardous piping line routes that invite use of handholds or climbing bars shall be avoided. Pressure lines and other components of at least 3,45 MPa and which are adjacent to safety-critical equipment shall be shielded to protect such equipment in the event of leakage or burst of pressure systems.

6.8 Electrical

6.8.1 Hazardous atmospheres

Electric components for use in potentially ignitable atmospheres shall be demonstrated to be incapable of causing an explosion in the intended application.

6.8.2 Radio frequency energy

Electrically energized hydraulic components shall not propagate radio frequency energy that is hazardous to other subsystems in the total system, or that interferes in the operation of safety-critical electronic equipment.

6.8.3 Grounding

Pressure system components, including lines to metallic structures, shall be electrically grounded.

6.8.4 Solenoids

Unless otherwise specified, all solenoids shall be capable of safely withstanding a test voltage of no less than 1 500 V(r.m.s.) at 60 cycle/s for 1 min between terminals and case at the maximum operating temperature of the solenoid in the functional envelope.

6.8.5 Electric motor-driven pumps

Electric motor-driven pumps used in safety-critical systems shall not be used for ground test purposes unless the motor is rated for reliable, continuous and safe operation.

6.9 Pressure relief

6.9.1 General requirements

Pressure relief devices shall be specified on any system having a pressure source that can exceed the MAWP of the system, or where the malfunction/failure of any component can cause the MAWP to be exceeded.

Relief devices are required downstream of all regulating valves and orifice restrictors unless the downstream system is designed to accept full source pressure. On space systems where operational or weight limitations preclude the use of relief valves and where systems will operate in an environment not hazardous to personnel, relief valves may be omitted if the ground or support system contains such devices and they cannot be isolated from the airborne system during the pressurization cycle and the space system cannot provide its own protection.

6.9.2 Flow capacity

All pressure relief devices shall provide relief at full flow capacity at 110 % of the MEOP of the system or lower.

6.9.3 Sizing

The size of pressure relief devices shall be specified to withstand specified maximum pressure and flow capacities of the pressure source in order to prevent pressure exceeding 110 % of the MEOP of the system.

6.9.4 Unmanned flight vehicle servicing

Where it is around a system that is specifically designed to service an unmanned flight vehicle, pressure relief protection may be provided within the ground equipment if no capability exists to isolate the pressure relief protection from the flight vehicle during the pressurization cycle.

6.9.5 Automatic relief

6.9.5.1 Low safety factor

Where safety factors of less than 2,0 are used in the design of pressure vessels, means of automatic relief, depressurization and pressure verification of safety-critical vessels shall be provided in the event of launch abort.

6.9.5.2 Confinement

Whenever any pressure volume can be confined and/or isolated, an automatic pressure relief device shall be provided, e.g. pop-valves, rupture discs, blowout plugs, armouring and construction, to contain the greatest possible overpressure that may develop.

6.9.6 Venting

Pressure relief devices for toxic or inert gases shall be vented to safe areas or scrubbers, away from the vicinity of personnel.

6.9.7 Relief valve isolation

Shutoff valves for the purpose of maintenance on the inlet side of pressurized relief valves are permissible if a means for monitoring and bleeding trapped pressure is provided and the provisions of 6.3 are met. The valve shall be locked open when the system is repressurized.

6.9.8 Negative-pressure protection

6.9.8.1 Testing

Hydrostatic testing systems for vessels that are not designed to sustain negative internal pressure shall be equipped with fail-safe devices for relief of hazardous negative pressure during the period of fluid removal. Check valves and valve interlocks are examples of devices that can be used for this purpose.

6.9.8.2 Storage and transportation

Thin-wall vessels that can be collapsed by a negative pressure shall have negative pressure relief and/or prevention devices for safety during storage and transportation.

6.9.9 Reservoir pressure relief

Pressurized reservoirs shall be so designed that ullage volume is connected to a relief valve that shall protect reservoir and power pump from hazardous overpressure or back pressure of the system.

6.9.10 Air pressure control

The air pressure control for pressurized reservoirs shall be an externally non-adjustable pressure-regulating device. If this unit also contains a reservoir pressure relief valve, the unit shall be designed so that no failure in the unit will permit over-pressurization of the reservoir.

6.10 Control devices

6.10.1 Directional control valves

Safety-critical pressure systems shall be designed to incorporate two or more directional control valves to preclude the possibility of inadvertently directing the flow or pressure from one valve into the flow or pressure path intended for another valve, with any combination of valve settings possible in the total system.

6.10.2 Overtravel

Control devices shall be designed to prevent overtravel or undertravel that may contribute to a hazardous condition or damage to the valve.

6.10.3 Pressure and volume control stops

All pressure and volume controls shall have stops, or an equivalent device, to prevent setting outside their nominal safe working range.

6.10.4 Manually operated levers

Integrated, manually operated levers and stops shall be capable of withstanding the limit torques shown in Table 1. Other limits can be specified if approved by the procuring authority.

Table 1 — Limit design torque for levers

Lever radius R mm	**Design torque** N·m
$R < 76{,}2$	$0{,}223 \times R$
$76{,}2 \leqslant R < 152{,}4$	$0{,}334 \times R$
$152{,}4 \leqslant R$	$0{,}668 \times R$

6.11 Accumulators

6.11.1 Accumulator design

Accumulators shall be designed in accordance with the pressure vessel standards for ground systems, and shall be located for minimal probability of mechanical damage and for minimum escalation of material damage or personnel injury in the event of a major failure such as vessel rupture.

6.11.2 Accumulator gas pressure gauges

Accumulator gas pressure gauges shall not be used to indicate system pressure for operational or maintenance purposes.

6.11.3 Accumulator identification

Gas type and pressure level shall be posted on, or immediately adjacent to, the accumulator.

6.12 Flexhose

6.12.1 Installation

Flexhoses shall be used between any two connections where relative motion can be expected to fatigue metal tube or pipe. Flexhose installations shall be designed to avoid abrasive contact with adjacent structures or moving parts. Rigid supports shall not be used on flexhoses.

6.12.2 Restraining devices

Unless otherwise specified, flexhose installations shall be at least 1,83 m long to ensure that restraint is provided on both the hose and adjacent structure at intervals of no more than 1,83 m and at each end in order to prevent whiplash in the event of a burst. Restraining devices shall be designed to constrain a force at least 1,5 times the open line pressure force, as calculated by the recommended methods shown in Table B.1. The design safety factor of the restraining device shall be at least 3. Placing sand or shot bags on top of flexhoses is not acceptable. Hose-clamp-type restraining devices shall not be used.

6.12.3 Flexhose stress

Flexhose installations shall be designed such that no significant stress or strain of any nature can be produced in the hard lines or components. This includes stress induced because of dimensional changes caused by pressure or temperature variations, or torque forces induced in the flexhoses.

6.12.4 Temporary installations

Temporary installations using chains or cables anchored to substantial fixed points, lead ingots or other weights are acceptable, providing they meet the requirements of 6.3.1. Flexhoses shall be protected from kinking, abrasive chafing from the restraining device, and damage from adjacent structures or moving parts that may cause reduction in strength.

7 Specific pressure system requirements

7.1 General

This clause presents specific requirements for hydraulic systems and pneumatic systems used in space vehicles and launch vehicles. These pressure systems shall also meet the general requirements of Clause 5.

7.2 Hydraulic systems

7.2.1 Hydraulic system components

7.2.1.1 Component selection and safety test

Selected components shall be compatible with, and rated for, the viscosity of the hydraulic fluid to be used.

When the system pressure is indeterminate, tests shall be performed at pressures no lower than 67 % of MAWP for components rated up to 20,7 MPa, and no lower than 80 % of the MAWP for components rated above 20,7 MPa.

7.2.1.2 Cycling

Cycling capability for safety-critical components shall be not less than four times the total number of expected cycles, including system tests, but not less than 2 000 cycles. For service above 71 °C, an additional cycling capability equivalent to the above shall be required as a maximum.

7.2.1.3 Actuators

Safety-critical hydraulic actuators shall have positive mechanical stops at the extremes of safe motion.

7.2.1.4 Shutoff valves

Hydraulic fluid reservoirs and supply tanks shall be equipped with shutoff valves, operable from a relatively safe location in the event of a hydraulic-system emergency.

7.2.1.5 Variable response

Shuttle valves shall not be used in safety-critical hydraulic systems where the event of force balance on both inlet ports may occur, thus causing the shuttle valve to restrict flow from the outlet port.

7.2.1.6 Fire-resistant fluids

Fire-resistant or flameproof hydraulic fluid shall be used where system leakage can expose hydraulic fluid to potential ignition sources or is adjacent to a potential fire zone and where the possibility of flame propagation exists.

7.2.1.7 Accumulators

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

7.2.1.8 Adjustable orifices

Adjustable orifice restrictor valves shall not be used in safety-critical hydraulic systems.

7.2.1.9 Lock valves

7.2.1.9.1 When two or more hydraulic actuators are mechanically tied together, only one lock valve shall be used to hydraulically lock all the actuators.

7.2.1.9.2 Hydraulic lock valves shall not be used for safety-critical lockup periods likely to involve extreme temperature changes unless fluid expansion and contraction effects are deemed safe.

7.2.1.10 Hydraulic reservoir

Whenever possible, the hydraulic reservoir shall be located at the highest point in the system. If this is not possible in safety-critical systems, procedures shall be developed to detect air in actuators or other safety-critical components and to ensure that the system is properly bled prior to each use.

7.2.2 Pressure limit

Hydraulic system installations shall be limited to a maximum pressure of 103,5 MPa.

NOTE There is no intent to restrain development of systems capable of higher pressures; however, the employment of such systems shall be preceded by complete development and qualification that includes appropriate safety tests.

7.2.3 Cavitations

7.2.3.1 Inlet pressure

The inlet pressure of hydraulic pumps in safety-critical systems shall be specified to prevent cavitation effects in the pump passage or outlets.

7.2.3.2 Fluid column

Safety-critical hydraulic systems shall have positive protections against breaking the fluid column in the suction line during standby.

7.2.4 Hydraulic lockup

7.2.4.1 Emergency disengagement

Hydraulic systems that provide for manual takeover shall automatically disengage or allow bypass of the main hydraulic system upon the act of manual takeover.

7.2.4.2 Emergency bypass

7.2.4.2.1 Safety-critical hydraulic systems or alternate bypass systems provided for safety shall not be rendered inoperative because of back pressure under any conditions.

7.2.4.2.2 The system shall be designed so that a hydraulic lock resulting from an unplanned disconnection of a self-seating coupling or other component shall cause no damage to the system or adjacent property, or injury to personnel.

7.2.5 Pressure relief

7.2.5.1 Pump pressure relief

Hydraulic systems employing power-operated pumps shall include pressure-regulating devices and independent safety relief valves.

7.2.5.2 Thermal pressure relief

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 shall not be considered an acceptance method for providing thermal relief. The thermal relief valve setting shall not exceed 1 MPa above the value for the system relief valve setting. Vents shall outlet only to areas of relative safety from fire hazard. Hydraulic blowout fuses shall not be used in systems having temperatures above 71 °C.

7.2.5.3 Location

Pressure relief valves shall be located in hydraulic systems wherever necessary to ensure that the pressure in any part of a power system does not exceed the safe limit above the regulated pressure of the system.

7.3 Pneumatic-system requirements

7.3.1 Pneumatic-system components

7.3.1.1 Component integrity

Pneumatic components (other than pressure vessels) for safety-critical systems shall exhibit safe endurance against hazardous failure modes for at least four times the total number of expected cycles, including system tests. Pneumatic ground support emergency system components shall have safe endurance of a minimum of 5 000 cycles.

7.3.1.2 Configuration

The configuration of pneumatic components shall permit bleeding of entrapped moisture, lubricant, particulate material or other foreign matter hazardous to the system.

7.3.1.3 Compressors

Compressors shall be designed to sustain at least 2,5 times the delivery pressure, after allowance for loss of strength of the materials equivalent to that caused by 1 000 h ageing at 135 °C, as a minimum.

7.3.1.4 Actuators

Safety-critical pneumatic actuators shall have positive mechanical stops at the extremes of safe motion.

7.3.1.5 Adjustable orifice restrictors

Adjustable orifice restrictor valves shall not be used in safety-critical pneumatic systems.

7.3.2 Controls

Automatic disengagement or bypass shall be provided for pneumatic systems to allow for manual takeover in the event of a hazardous situation. Positive indication of disengagement shall be provided.

The recommended minimum proof test factor and design burst factor for each type of pressurized hardware item are shown in Table A.1.

Annex A
(informative)

Recommended minimum safety factors

The recommended minimum proof test factor and design burst factor for each type of pressurized hardware item are shown in Table A.1.

Table A.1 — Recommended minimum proof factors and design burst factors

Type of component		Proof factor	Design burst factor
Line and fitting	Diameter $<$ 38 mm	1,50	4,00
	Diameter $\geqslant$ 38 mm	1,50	2,50
Fluid return section		1,50	3,00
Fluid return hose		1,50	5,00
Other pressure components		1,50	2,50
NOTE 1 MEOP is the baseline external and internal pressure.			
NOTE 2 Pressure components subject to low or negative pressure are evaluated at 2,5 times MEOP.			

The recommended design ultimate factor for manned and unmanned systems are shown in Table A.2.

Table A.2 — Recommended minimum design ultimate load factor

Type of system	Design ultimate factor
Manned	1,4
Unmanned	1,25
NOTE Limit load is the baseline external load.	

Annex B
(informative)

Open line force calculation factors

Control components that have integral, manually operated levers are recommended to provide levers and stops capable of withstanding the limit torques as shown in Table B.1.

Table B.1 — Open line force calculation factors

Diameter opening mm	**Calculated force factor** N/kPa
3,175	5,8
5,080	8,8
9,525	12,0
12,700	15,0
15,875	18,0
19,050	21,0
22,225	24,0
25,400	27,0

To calculate the force acting on the line opening, select the applicable diameter and multiply the corresponding force factor (right-hand column in the table) by the source pressure, in kilopascals.

ICS 49.140

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