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11 December 2024

Space engineering

Structural design and verification of pressurized hardware

This document is distributed to the ECSS community for Public Review.

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Foreword

ECSS is a cooperative effort of the European Space Agency, national space agencies and European industry associations for the purpose of developing and maintaining common standards. Requirements in this Standard are defined in terms of what shall be accomplished, rather than in terms of how to organize and perform the necessary work. This allows existing organizational structures and methods to be applied where they are effective, and for the structures and methods to evolve as necessary without rewriting the standards.

This Standard has been prepared by the ECSS-E-ST-32-02C Working Group, reviewed by the ECSS Executive Secretariat and approved by the ECSS Technical Authority.

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Change log

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Next steps	
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DIA	Preparation of document for publication (including DOORS transfer for Standards)
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ECSS-E-ST-32-02A	Never issued
ECSS-E-ST-32-02B	Never issued
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ECSS-E-ST-32-02C Rev.2 DIR1 11 December 2024	NOTE: This Change log will be filled in by the Secretariat before the publication of the new standard. First issue revision 2.

	Changes with respect to ECSS-E-ST-32-02C Rev. 1 (15 November 2008) are identified with revision tracking. Main changes • Implementation of change requests • Xxxxx • Xxxxx **Detailed Change Record:** Deleted requirements: Xxxx Added requirements: Xxxxx Modified requirements: Xxxx Modified requirements where only a cross-reference was updated: XXXXX Modified headings: XXXX Editorial changes: • XXXX • YYYY

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1 Scope

This Standard defines the structural design verification of metallic and non-metallic pressurized hardware which includes pressure vessels, pressurized structures, pressure components (such as valves, pumps, lines, fittings, and hoses), and special pressurized equipment (e.g. batteries, heat pipes, cryostats, sealed containers, hazardous fluids container). Pressurized hardware is defined as hardware that 'primarily contains internal pressure', and therefore pressurized hardware (other than pressurized structures) that are subjected to significant loads other than internal pressure can require tailoring of the standardized structural design verification approach.

This standard provides a minimum set of requirements. Some topics are not covered fully by this standard. Topics not fully covered by this standard include:

- External supports and structural interfaces;
- Solid propellant motor cases;
- The following launcher liquid propulsion equipment: combustion chamber, gas generator, pre burner, turbopump, nozzle extension, igniter, mechanisms (according to ECSS-E-ST-35-03C, Liquid propulsion for launchers)
- Expulsion devices, including bladders and diaphragms;
- Functional requirements like rapid expulsion, cleanliness;
- Pressure components that experience significant non-pressure loads, for example bellows, flexible lines, thrusters;
- Relief devices, for example burst disks and relief valves; Pyro valves;
- Pressure system passivation, including definition of safe pressure;
- Demisability during re-entry;
- Inflatable pressurized hardware;
- Composite pressure components and composite special pressurized equipment;
- Non-metallic, non-composite pressurized hardware, including windows;
    - Note that homogeneous non-metallic liners are covered to some extent;
- Seals.

Objectives of the associated verification process are primarily to demonstrate the qualification of design and performance, as meeting all specified requirements, and to ensure that the flight hardware is free from workmanship defects and acceptable for flight.

This Standard applies to all space products and in particular to launch vehicles, transfer vehicles, re-entry vehicles, spacecraft, space station, landing probes and rovers, sounding rockets, payloads and instruments.

This standard, similar to other current pressurized hardware standards, does not cover in detail the requirements for application of additive manufacturing to pressurized hardware. The ECSS-Q-ST-70-80 is a good starting point, but the relevant structural standards, e.g. ECSS-E-ST-32 and ECSS-E-ST-32-01, and emerging standards at e.g. NASA indicate that the most critical applications, especially in case of applications in human spaceflight, can require more effort than currently required as minimum by ECSS-Q-ST-70-80.

This standard may be tailored for the specific characteristics and constraints of a space project in conformance with ECSS-S-ST-00.

Tailoring can involve complementing or replacing requirements of this standard with those of other standards that are made applicable, like ANSI/AIAA S-080 and ANSI/AIAA S-081 and NASA-STD-5019 or similar fracture control requirements documents. This can be especially relevant for human spaceflight applications.

2
Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this ECSS Standard. For dated references, subsequent amendments to, or revision of any of these publications, do not apply. However, parties to agreements based on this ECSS Standard are encouraged to investigate the possibility of applying the more recent editions of the normative documents indicated below. For undated references, the latest edition of the publication referred to applies.

ECSS-S-ST-00-01	ECSS system – Glossary of terms
ECSS-E-ST-10-02	Space engineering – Verification
ECSS-E-ST-10-03	Space engineering – Testing
ECSS-E-ST-32	Space engineering – Structural general requirements
ECSS-E-ST-32-01	Space engineering – Fracture control
ECSS-E-ST-32-08	Space engineering – Materials
ECSS-E-ST-32-10	Space engineering – Structural factors of safety for spaceflight hardware
ECSS-Q-ST-20	Space product assurance – Quality assurance
ECSS-Q-ST-70	Space product assurance – Materials, mechanical parts and processes
ECSS-Q-ST-70-15	Space product assurance – Non-destructive testing

3
Terms, definitions, and abbreviated terms

3.1 Terms from other standards

a. For the purpose of this Standard, the terms and definitions from ECSS-S-ST-00-01 apply and in particular the following:

1. acceptance, analysis, approval, assembly, baseline (TBC), capability, catastrophic, certification, component, composite, configuration, conformance, corrective action, critical, customer, defect, design, development, environment, equipment, failure, failure mode, hazard, inspection, interface, launch vehicle, life cycle, lifetime, lot, maintenance, material, mission, model, normative, part, payload, performance, procedure, process, product, product assurance, project, protoflight model (TBC), provision, qualification, quality, reliability, repair, requirement, safety, spacecraft, specification (TBC), standard, supplier, system, tailoring, test, thermal vacuum test, toxic, unit, verification

2. customer

NOTE Normally, the customer ensures that the requirements of the safety authority are taken into account.

b. For the purpose of this Standard, the terms and definitions from ECSS-E-ST-32 apply and in particular the following:

1. maximum design pressure (MDP)

2. maximum expected operating pressure (MEOP)

c. For the purpose of this Standard, the terms and definitions from ECSS-E-ST-32-01 apply.

3.2 Terms specific to the present standard

3.2.1 autofrettage

vessel sizing operation where pressure driven deflection is used to plastically yield the metal liner into the overlying composite in order to induce initial compressive stress states in the metal liner

NOTE Autofrettage is considered to be part of the manufacturing process and is conducted prior to acceptance test.

3.2.2 boss

zone of a pressure vessel or a pressurized structure ensuring functional interfaces of the hardware with the pressurized system

NOTE Examples of functional interfaces are fluid connections and mechanical interfaces. The boss is generally located in the dome region of the pressurized shell.

3.2.3 burst factor (j_{burst})

multiplying factor applied to the maximum design pressure (MDP), to obtain the design burst pressure

NOTE The burst factor corresponds to an ultimate factor of safety.

3.2.4 burst pressure

pressure level at which collapse, rupture or unstable fracture of the pressurized hardware occurs

3.2.5 composite over-wrap

layers of fibre-based composite material applied onto a liner, sustaining significant pressure and environmental loads

3.2.6 composite over-wrapped pressure vessel (COPV)

pressure vessel with a fibre-based composite structure fully or partially encapsulating a liner

NOTE For example:

- the liner can be metallic or not.
- the liner ensures the leak tightness of the vessel.

3.2.7 composite over-wrapped pressurized component (COPC)

pressurized component with a fibre-based composite system fully or partially encapsulating a liner

NOTE 1 For example:

- the liner can be metallic or not.
- the liner ensures the leak tightness of the vessel.

NOTE 2 In this standard COPC are treated very similar to COPV because heritage is limited. A tailored approach agreed between customer and supplier, who also represent relevant safety authorities, can be appropriate. The tailored approach includes for example similarity with the requirements for metallic PC while addressing also concerns associated with composite elements.

3.2.8 composite over-wrapped pressurized structure (COPS)

pressurized structure with a fibre-based composite system fully or partially encapsulating a liner

NOTE For example:

- the liner can be metallic or not.
- the liner ensures the leak tightness of the vessel.

3.2.9 composite over-wrapped special pressurized equipment (COSPE)

special pressurized equipment with a fibre-based composite system fully or partially encapsulating a liner

NOTE 1 For example:

- the liner can be metallic or not.
- the liner ensures the leak tightness of the vessel.

NOTE 2 In this standard COSPE are treated very similar to COPV because heritage is limited. A tailored approach agreed between customer and supplier, who also represent relevant safety authorities, can be appropriate. The tailored approach includes for example similarity with the requirements for metallic SPE while addressing also concerns associated with composite elements.

3.2.10 composite pressure vessel (CPV)

pressure vessel whose structural wall is fully composed with fibre based composite material

NOTE For example:

- the permeation barrier can be ensured by a coating on the internal or the external shape of the composite wall, or by the composite wall itself, or by both.
- low-pressure liquid hydrogen tank without liner.

3.2.11 composite pressurized structure (CPS)

pressurized structure whose structural wall is fully composed with fibre based composite material

NOTE For example:

- the permeation barrier can be ensured by a coating on the internal or external shape of the composite wall, or by the composite wall itself, or by both.
- low-pressure liquid hydrogen structural tank without liner.

3.2.12 critical flaw

specific flaw with a size such that unstable growth occurs under the specific operating load and environment

3.2.13 cryostat

vacuum-jacketed container designed to keep its contents at a low (cryogenic) temperature

NOTE Cryostat is also known as a Dewar, named after its inventor.

3.2.14 design burst pressure

differential pressure to be withstood by the pressurized hardware without burst in the applicable operating environment

NOTE The design burst pressure is equal to the product of the MDP and the burst factor.

3.2.15 differential pressure

internal pressure minus external pressure

3.2.16 environmental correction factor (ECF)

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

NOTE 1 The ECF is generally determined by the ratio of the relevant strength property at test temperature and worst specified environment for the test, but it can be necessary to consider other phenomena.

NOTE 2 The ECF for the proof test, cycle test and burst test can be different. For a test with fracture objective, using a cracked test article, the ECF is normally based on fracture properties

NOTE 3 In most cases, temperature is the dominant environmental effect defining the ECF.

NOTE 4 ECF smaller than 1 are usually not applied.

3.2.17 external pressure

absolute pressure outside the pressurized hardware

3.2.18 fibre failure

rupture or kinking of a bundle of filaments

NOTE There are two fibre failure modes: under tension (fibre rupture) and under compression (kinking).

3.2.19 fitting

pressure component of a pressurized system utilized to connect lines, other pressure components or pressure vessels within the system

3.2.20 hazardous fluid container

pressurized container, compartment or housing that primarily contains internal pressure and that is individually sealed to contain a fluid with an energy level smaller than 19310 Joules, and with a pressure smaller than 0,15 MPa, which can create a hazard if released.

NOTE 1 Clause 8.2.6 of ECSS-E-ST-32-01 defines limited fracture control verification approaches, as well as reduced proof and burst factor requirements, for metallic sealed containers that respect these stored energy and pressure limits. For other hazardous fluid containers clause 8.2.6 of ECSS-E-ST-32-01 specifies that they are treated and certified the same as pressure vessels.

NOTE 2 Sometimes tailoring is applied when agreed between customer and supplier, who also represent relevant safety authorities, for example by similarity with the requirements for pressure components, rather than applying pressure vessel requirements.

3.2.21 homogeneous non-metallic liner

a liner fabricated with a polymeric material, either thermoset or thermoplastic.

NOTE 1 Examples include polyvinyl chloride, polyethylene, polyamide, and polytetrafluoroethylene. More brittle polymers like epoxy and phenolic are generally less suitable for application as liner for pressurized hardware.
AIAA G-082-2022 can provide useful additional information.

NOTE 2 Requirements for non-metallic liner materials other than polymeric materials are not covered by this standard and need to be addressed by tailoring.

3.2.22 hydrogen embrittlement

mechanical and environmental process that results from the initial presence or absorption of excessive amounts of hydrogen in metals

NOTE Usually it occurs in combination with residual or applied tensile stresses.

3.2.23 impact damage

induced defect caused by an object strike on the pressurized hardware or pressurized hardware strike on an object

NOTE Delamination in the composite over-wrap of a COPV, dent in the metallic liner of a COPV.

3.2.24 inter-fibre failure

micro-cracking in the matrix of a composite material, or at the interface filament-matrix of a composite material

3.2.25 internal pressure

absolute pressure inside the pressurized hardware

3.2.26 leak-before-burst (LBB)

fracture mechanics design concept, showing that any potentially critical flaw grows through the wall of a pressurized system and cause pressure relieving leakage at MDP without burst (catastrophic failure)

NOTE LBB is not intended as a safety measure against over-pressurization or combined loads.

3.2.27 liner

part of pressurized hardware serving as a mandrel during the manufacturing of the over-wrap and as fluid permeation barrier when in contact with the stored fluid

NOTE For example:

- when the liner is made of metallic material, it can carry significant pressure and environmental loads.
- when the liner is made of homogeneous non metallic material, it usually does not carry significant pressure and environmental loads.

3.2.28 line

tubular pressurized hardware of a pressurized system provided as means for transferring fluids between components of the system

NOTE Flex hoses are included.

3.2.29 mechanical damage

induced flaw in pressurized hardware item which is caused by surface abrasions, cuts or impacts

NOTE The pressurized hardware item can be a metallic, homogeneous non metallic or composite item.

3.2.30 metallic pressure vessel (MPV)

pressure vessel fully composed of metallic material

3.2.31 metallic pressurized structure (MPS)

pressurized structure fully composed of metallic material

3.2.32 metallic pressurized component (MPC)

pressurized component fully composed of metallic material

3.2.33 metallic special pressurized equipment (MSPE)

special pressurized equipment fully composed of metallic material

3.2.34 non-hazardous LBB (NHLBB) failure mode

leak-before-burst (LBB) behaviour that does not result in a hazard

NOTE For example: LBB behaviour with a leak of liquid or gas that is not toxic, reactive or flammable and that does not fulfil a safety critical function.

3.2.35 pressure component (PC)

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

NOTE 1 For example:

- lines, fittings, gauges, valves, bellows, and hoses.

NOTE 2 For pressure components subjected to significant loads not caused by internal pressure, acceptance proof and leak testing with only internal pressure can be inadequate.

NOTE 3 Classification as pressure component of components that exceed energy or pressure limits of the pressure vessel definition, is normally subject to agreement between customer and supplier, who also represent relevant safety authorities, on a case by case basis.

3.2.36 pressure vessel (PV)

pressurized hardware designed primarily for the storage of pressurized fluid with an energy level greater than or equal to 19310 Joules, or with a pressure greater than or equal to 0,69 MPa, or with a pressure greater than or equal to 0,10 MPa which can create a hazard if released

NOTE 1 E.g. the stored energy can be calculated by the formula for the reversible adiabatic (isentropic) expansion of the confined gas:

$$E = \frac{P_1 V}{\gamma - 1}\left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}\right]$$

where:

E is the stored energy;

P_1 is the internal pressure;

P_2 is the external pressure;

V is the pressurized volume;

γ is the ratio of specific heat of the gas.

NOTE 2 Whether a pressurized hardware is considered to be 'designed primarily for the storage of pressurized fluid' can be subjective. Classification as pressure vessel or otherwise of pressurized hardware, that exceed energy or pressure limits of this definition, is normally subject to agreement between customer and supplier, who also represent relevant safety authorities, on a case by case basis.

3.2.37 pressurized hardware (PH)

hardware item that primarily contains internal pressure

NOTE 1 E.g. included are pressure vessels, pressurized structures, pressure components and special pressurized equipments.

NOTE 2 For pressurized hardware subjected to significant loads not caused by internal pressure, acceptance proof and leak testing with only internal pressure can be inadequate.

3.2.38 pressurized structure (PS)

structure designed to carry both internal pressure and vehicle structural loads

NOTE 1 E.g. launch vehicle main propellant tanks, crew cabins and manned modules.

NOTE 2 Whether a pressurized hardware is considered to be pressurized structure can be subjective. Classification as pressure vessel or pressurized structure of pressurized hardware, that exceed energy or pressure limits of the pressure vessel definition, is normally subject to agreement between customer and supplier, who also represent relevant safety authorities, on a case by case basis. Increased proof and burst factors can sometimes apply, for example when people are working nearby.

3.2.39 pressurized system

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

NOTE 1 For example:

- a pressurized system is often called a pressure system.
- electrical or other control devices for system operations are not included.

NOTE 2 For a pressurized system subjected to significant loads not caused by internal pressure, acceptance

proof and leak testing with only internal pressure can be inadequate.

3.2.40 proof factor (j_{proof})

multiplying factor applied to MDP to obtain design proof pressure

3.2.41 proof pressure

product of MDP and proof factor

3.2.42 proof test

test of flight hardware under proof load or pressure to give evidence of satisfactory workmanship and material quality or to establish the initial crack sizes in the hardware

3.2.43 sealed container

pressurized container, compartment or housing that primarily contains internal pressure and that is individually sealed to contain a fluid or to maintain an internal gaseous environment with an energy level smaller than 19310 Joules, and with a pressure smaller than 0,69 MPa, which will not create a hazard if released

NOTE 1 E.g. electronics housing

NOTE 2 Clause 8.2.5 of ECSS-E-ST-32-01 defines limited fracture control verification approaches, as well as reduced proof and burst factor requirements, for metallic 'low risk' sealed containers that have a stored energy potential that does not exceed 19310 joules, have a pressure shell is that is verified leak before burst, and have an MDP less than 0,30 MPa.

NOTE 3 For sealed containers subjected to significant loads not caused by internal pressure, acceptance proof and leak testing with only internal pressure can be inadequate.

NOTE 4 Sometimes tailoring is applied when agreed between customer and supplier, who also represent relevant safety authorities, for example by similarity with the requirements for pressure components, rather than applying safe life requirements.

3.2.44 sizing pressure

pressure to which composite over-wrapped pressurized hardware is subjected with the intent of yielding its metallic liner or a portion of the liner

NOTE E.g. the sizing pressure also refers to the pressure applied during autofrettage.

3.2.45 special pressurized equipment

pressurized hardware that primarily contains internal pressure and for which a special development and verification approach applies

NOTE 1 For example:

- Classification as special pressurized equipment is subject to customer approval, per 4.1.2.f.
- heat pipes, loop heat pipes, capillary pumped loops, cryostats, sealed containers and hazardous fluids container.

NOTE 2 For special pressurized equipment subjected to significant loads not caused by internal pressure, acceptance proof and leak testing with only internal pressure can be inadequate.

NOTE 3 Classification as special pressurized equipment of components that exceed energy or pressure limits of the pressure vessel definition, is normally subject to agreement between customer and supplier, who also represent relevant safety authorities, on a case-by-case basis.

3.2.46 stress rupture

sudden failure mode for composite structural items that can occur at normal operating pressures and environments

NOTE This failure mode can occur while at stress levels below ultimate strength for an extended time. It can affect COPV, CPV, COPS, CPS, COPC and COSPE. The failure mechanism is complex, not well understood, and difficult to accurately predict or detect prior to failure. Pressure, duration of time at pressure, and environment experienced contribute to the degradation of the fiber and/or the fiber-matrix interface, particularly around accumulations of fiber breaks, and these increase the probability of stress rupture of composite structural items.

3.2.47 visual damage threshold (VDT)

lowest impact energy level applied to a composite item that creates an indication that is detectable by an inspector using an unaided visual technique

NOTE No quantitative reliability nor confidence level is associated with this technique.

3.3 Abbreviated terms

For the purpose of this Standard, the abbreviated terms from ECSS-S-ST-00-01 and the following apply:

Abbreviation	Meaning
BAI	residual burst strength after impact
COPC	composite over-wrapped pressurized component

COPS	composite over-wrapped pressurized structures
COSPE	composite over-wrapped special pressurized equipment
COPV	composite over-wrapped pressure vessel
CPS	composite pressurized structure
CPV	composite pressure vessel
DLL	design limit load
DUL	design ultimate load
DYL	design yield load
ECF	environmental correction factor
FCI	fracture critical item
FLLI	fracture limited life item
FOS	factor of safety
ISS	international space station
LBB	leak-before-burst
MDP	maximum design pressure
MEOP	maximum expected operating pressure
MPC	metallic pressurized component
MPS	metallic pressurized structure
MPV	metallic pressure vessel
MSPE	metallic special pressurized equipment
NDT	non-destructive testing
NHLBB	non-hazardous leak-before-burst
PFCI	potential fracture-critical item
PC	pressure component
PH	pressurized hardware
PV	pressurized pressure vessel
PS	pressurized structure
SPE	special pressurized equipment
VDT	visual damage threshold

3.4 Symbols

j_{burst}	value of burst factor
j_{proof}	value of proof factor
FOSU	value of ultimate factor of safety
FOSY	value of yield factor of safety

3.5 Nomenclature

The following nomenclature applies throughout this document:

a. The word "shall" is used in this Standard to express requirements. All the requirements are expressed with the word "shall".

b. The word "should" is used in this Standard to express recommendations. All the recommendations are expressed with the word "should".

NOTE It is expected that, during tailoring, recommendations in this document are either converted into requirements or tailored out.

c. The words "may" and "need not" are used in this Standard to express positive and negative permissions, respectively. All the positive permissions are expressed with the word "may". All the negative permissions are expressed with the words "need not".

d. The word "can" is used in this Standard to express capabilities or possibilities, and therefore, if not accompanied by one of the previous words, it implies descriptive text.

NOTE In ECSS "may" and "can" have completely different meanings: "may" is normative (permission), and "can" is descriptive.

e. The present and past tenses are used in this Standard to express statements of fact, and therefore they imply descriptive text.

4
General requirements

4.1 Classification

4.1.1 General

The pressurized hardware treated in this Standard are categorized in .

As mentioned in the Scope of this standard, tailoring can involve complementing or replacing requirements of this standard with those of other standards that are made applicable, like ANSI/AIAA S-080 and ANSI/AIAA S-081 and NASA-STD-5019 or similar fracture control requirements documents. This can be especially relevant for human spaceflight applications, as also addressed in clause 8.2.1.a of ECSS-E-ST-32-01C rev.2.

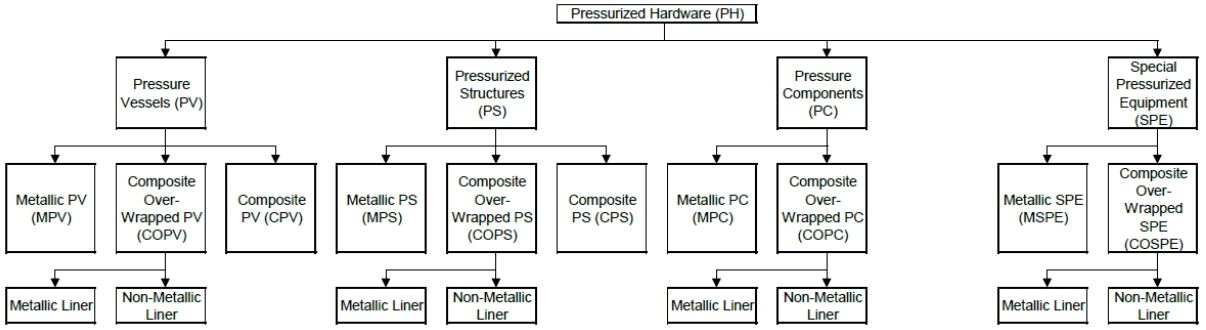

Figure 4-1: Breakdown of PH types covered by this Standard

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4.1.2 Classification of pressurized hardware

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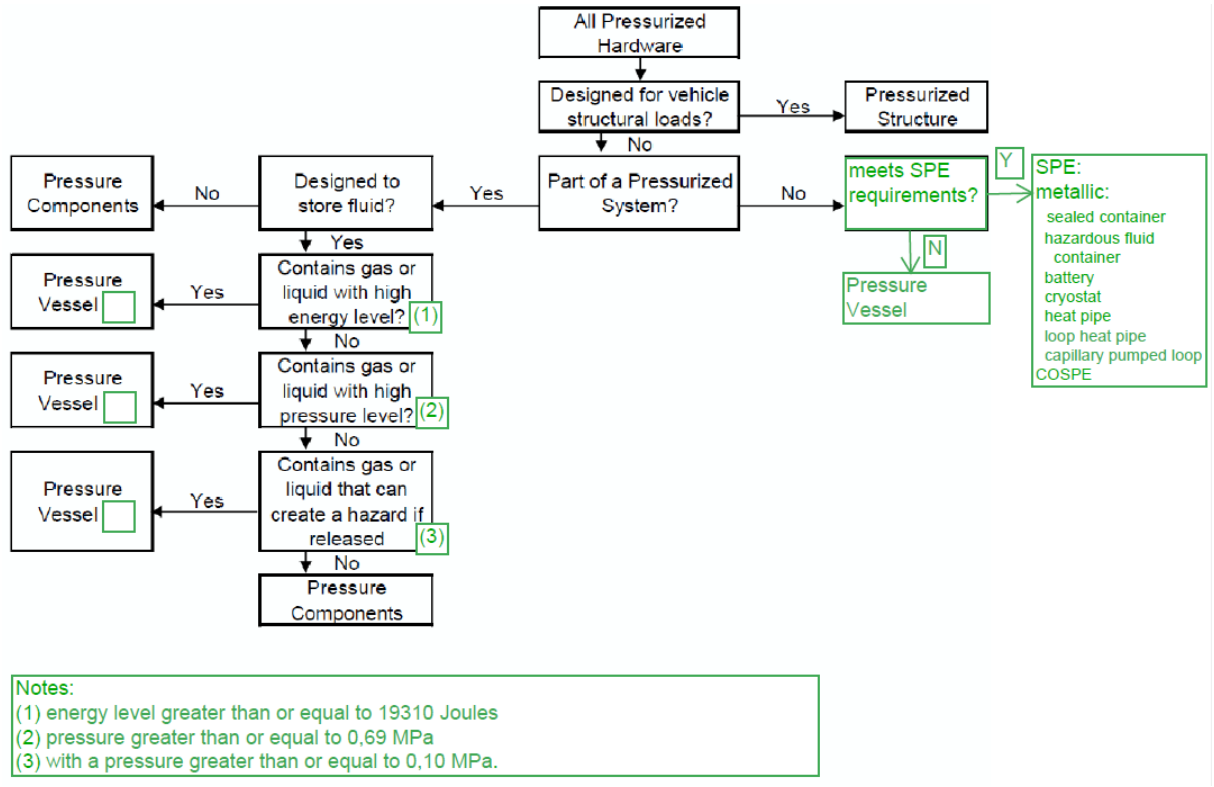

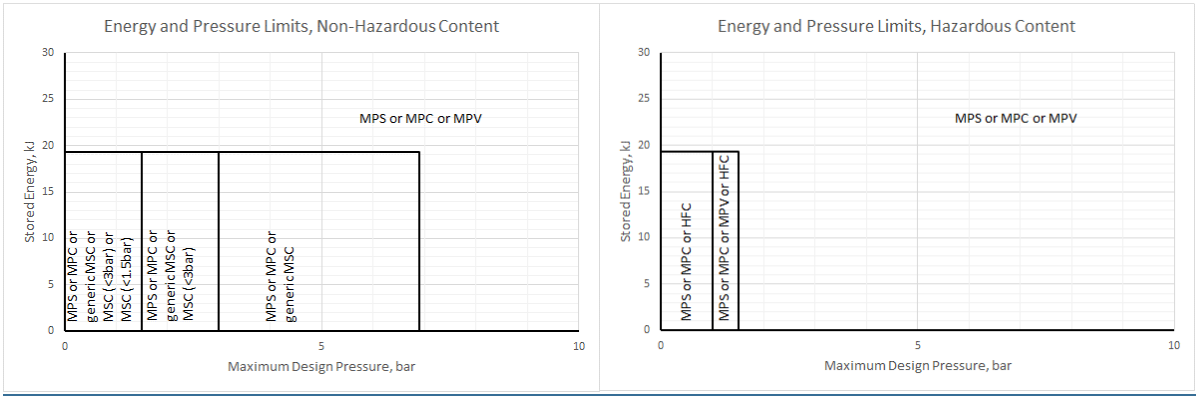

Figure 4-2: Flowchart describing PH classifications covered by this Standard

a. Pressurized hardware shall be classified in accordance with the flowchart of Figure 4-2.

b. All classes of pressurized hardware (PH) shall meet the requirements specified in clause 4.2.

c. All pressure vessels (PV) shall meet the requirements specified in clause 4.3.1 and one of the following depending on the hardware type: 4.3.2, 4.3.3, 4.3.4.

d. All pressurized structures (PS) shall meet the requirements specified in clause 4.4.1 and one of the following depending on the hardware type: 4.4.2, 4.4.3, 4.4.4.

e. All pressure components (PC) shall meet the requirements specified in clause 4.5.1 or 4.5.2 or 4.5.3 depending on the hardware type.

f. Classification as special pressurized equipment (SPE) shall be subject to customer approval.

g. All special pressurized equipment (SPE) types shall meet the requirements specified in clause 4.6.1 or 4.6.2 or 4.6.3 depending on the hardware type.

h. For hardware that does not meet all applicable requirements of one of the classes, the applicable requirements shall be agreed between customer and supplier as part of tailoring.

4.2 General

4.2.1 Leak tightness

ECSS-E-ST-32-02_0260001

a. The maximum acceptable leak rates of the pressurized hardware versus pressure values shall be established through a detailed analysis of the pressurized system to which the pressurized hardware belongs.

ECSS-E-ST-32-02_0260002

b. Leak rate of all pressurized hardware shall conform to the level defined in 4.2.1a.

ECSS-E-ST-32-02_0260003

c. Leak rate of all pressurized hardware shall be such that operation of the system is ensured throughout the specified lifetime.

NOTE Pressurized hardware containing hazardous fluids reach end of safe-life when leakage occurs.

4.2.2 Fracture control and fracture critical parts

ECSS-E-ST-32-02_0260004

a. Fracture critical item classification and verification shall be performed in conformance with ECSS-E-ST-32-01.

NOTE When pressurized hardware is classified as fracture critical, it is subjected to the implementation of the fracture critical item tracking, control, verification and documentation procedures specified in ECSS-E-ST-32-01.

b. Fracture control for non-fracture critical PFCI shall be implemented in conformance with ECSS-E-ST-32-01.

NOTE 1 Not all pressurized hardware are fracture critical but they can still require implementation of fracture control measures. The ECSS-E-ST-32-01 requests a fracture control plan which describes the planned fracture control activities.

NOTE 2 In case a safe life demonstration by test is foreseen, requirement 6.3.1.b of ECSS-E-ST-32-01 requests that the methodology applied for evaluation by test is subject to customer approval. Additional guidance on damage tolerance verification specifically of pressurized hardware by test can be found, for example, in ANSI/AIAA S-080A-2018, ANSI/AIAA S-081B-2018 and AIAA G-082-2022.

4.2.3 Operation and maintenance

4.2.3.1 Operating procedures

ECSS-E-ST-32-02_0260005

a. Operating procedures shall be established for all pressurized hardware.

ECSS-E-ST-32-02_0260006

b. The procedures specified in 4.2.3.1a shall be compatible with the safety requirements and personnel control requirements at the facility where the operations are conducted.

NOTE This includes compliance with range safety requirements, transportation requirements. These can drive specific safety factors or acceptance tests.

ECSS-E-ST-32-02_0260007

c. Step-by-step directions shall be written with such a detail to unambiguously describe the operation.

ECSS-E-ST-32-02_0260008

d. Schematics identifying the location and pressure limits of a relief valve and burst disc, shall be provided.

ECSS-E-ST-32-02_0260009

e. Procedures to ensure compatibility of the pressurizing system with the structural capability of the pressurized hardware shall be established.

ECSS-E-ST-32-02_0260010

f. Prior to initiating or performing a procedure involving hazardous operations with pressure systems, practice runs shall be conducted on non-pressurized systems.

ECSS-E-ST-32-02_0260011

g. Initial tests shall then be conducted at pressure levels not to exceed 50 % of the nominal operating pressure until operating characteristics can be established.

ECSS-E-ST-32-02_0260012

h. Warning signs with the hazard identified shall be posted at the operations facility prior to pressurization.

i. The operating procedures shall incorporate or reference damage control measures.

NOTE Damage control measures describe how composite pressurized hardware will be protected from detrimental damage due to impacts during manufacturing, handling, transportation, assembly, and integration. The operating procedures also describes how this will be supported by inspections to be performed according to clause 5.7 throughout the life of the vessel. In many cases a dedicated plan is provided or requested, sometimes at higher assembly level, addressing all operations until the hardware is no longer accessible for damage.

For an example of a damage control plan describing damage control measures for a COPV, see JSC 66901.

4.2.3.2 Safe operating limit

ECSS-E-ST-32-02_0260013

a. Safe operating limits shall be established for pressurized hardware based on analysis and testing employed during its design, development and qualification.

ECSS-E-ST-32-02_0260014

b. The safe operating limits specified in 4.2.3.2a shall be summarized in a format providing visibility of the structural characteristics and capability.

ECSS-E-ST-32-02_0260015

c. The information in the format specified in 4.2.3.2b shall include as a minimum the following data:

1. In a general case
   (a) fabrication materials;
   (b) critical design conditions;
   (c) MDP;
   (d) nominal operating pressure;
   (e) proof pressure;
   (f) design burst pressure;
   (g) pressurization and depressurization sequence;
   (h) operational cycle limits;
   (i) operational system fluid;
   (j) cleaning agent;
   (k) NDT techniques employed;
   (l) extreme thermal and chemical environments;
   (m) maximum leakage levels versus pressure values;
   (n) minimum margin of safety;
   (o) potential failure mode.
2. For pressurized hardware with a non LBB failure mode, additionally to the data included in 4.2.3.2c.1:
   (a) the critical flaw sizes;
   (b) the maximum acceptable flaw sizes.

ECSS-E-ST-32-02_0260016

d. Back-up documentation, including at least applicable references to design drawings, detail analyses, inspection records, and test reports, shall be indicated.

ECSS-E-ST-32-02_0260017

e. The minimum internal pressure to guaranty structural stabilization shall be identified and included in the acceptance data package.

4.2.3.3 Inspection and maintenance

ECSS-E-ST-32-02_0260018

a. The results of stress and safe-life analyses shall be used in conjunction with the results from the structural development and the qualification tests to define quantitative acceptance criteria for inspection and repair.

ECSS-E-ST-32-02_0260019

b. Damage limits shall be established by the supplier for pressurized hardware so that the inspection interval and repair schedule can be established.

ECSS-E-ST-32-02_0260020

c. Analyses of operational data developed per clause 5.7 shall include forecast of remaining life and reassessment of inspection intervals.

4.2.3.4 Repair

ECSS-E-ST-32-02_0260021

a. All repaired or refurbished hardware shall be submitted to re-acceptance, as specified in clause 4.2.4.3, after each repair and refurbishment to verify their structural integrity.

4.2.3.5 Storage

ECSS-E-ST-32-02_0260022

a. When pressurized hardware is put into storage:

1. they shall be protected against exposure to adverse environments that can cause corrosion or degrade the material;
2. they shall be protected against mechanical damages;
3. induced stresses due to storage fixture constraints shall be avoided by storage fixture design.

ECSS-E-ST-32-02_0260023

b. If 4.2.3.5a is not met, the hardware shall be submitted to re-acceptance as specified in clause 4.2.4.3 prior to acceptance for use.

4.2.3.6 Documentation

ECSS-E-ST-32-02_0260024

a. Inspection, maintenance, and operation records shall be kept and maintained throughout the life of the pressurized hardware.

ECSS-E-ST-32-02_0260025

b. As a minimum, the records specified in 4.2.3.6a shall contain the following information:

1. temperature, pressurization history, and pressurizing fluid for both tests and operations;
2. number of pressurization cycles experienced as well as the maximum number in safe-life analysis or test;

3. results of any inspection conducted, including: inspector, inspection dates, inspection techniques employed, location and character of flaws, flaw origin and cause;
4. storage condition;
5. maintenance and corrective action performed from manufacturing to operational use, including refurbishment;
6. sketches and photographs to show areas of structural damage and the extent of repair;
7. acceptance and re-acceptance test performed, including test condition and results;
8. analyses supporting the repair or modification which can influence future use capability.

4.2.4 Service life extension, reactivation and re-acceptance

4.2.4.1 Service life extension

ECSS-E-ST-32-02_0260437

a. In case of safe-life demonstration, required for the hardware, the service life may be extended after performing a complete NDT, and leak test.

ECSS-E-ST-32-02_0260438

b. In case of fatigue life demonstration, required for the hardware, the service life may be extended without additional test or inspection, if there is available data including at least actual pressure, loads, and environments from the past period of service life, and the evaluation exhibits that the cumulative damage does not reach the specified service life.

ECSS-E-ST-32-02_0260028

c. The new service life shall be determined by fatigue-life or safe-life demonstration as required for this type of pressurized hardware.

4.2.4.2 Reactivation

ECSS-E-ST-32-02_0260029

a. Pressurized hardware which is reactivated for use after an extensive period in either an unknown, unprotected, or unregulated storage environment shall meet the requirements specified in clause 4.2.4.3 to ascertain their structural integrity before commitment to flight.

ECSS-E-ST-32-02_0260030

b. A specific inspection for corrosion and incidental damage prior to re-acceptance tests shall be performed.

4.2.4.3 Re-acceptance

ECSS-E-ST-32-02_0260031

a. All refurbished pressurized hardware shall undergo the same acceptance tests as specified for new hardware in clauses 4.2.5 to 4.6, in order to verify their structural integrity before commitment to flight.

ECSS-E-ST-32-02_0260032

b. If the demonstration specified in 4.2.4.3a is not performed, it shall be demonstrated that the refurbished parts of the pressurized hardware are not affected by the corresponding tests.

ECSS-E-ST-32-02_0260033

c. Pressurized hardware exceeding the specified storage environment shall undergo the acceptance tests specified in clauses 4.2.5 to 4.6 for new hardware.

NOTE Specified storage environment includes for example temperature, humidity, time and storage fixture constraints.

ECSS-E-ST-32-02_0260034

d. If the demonstration specified in 4.2.4.3c is not performed, it shall be demonstrated that all concerned parts of the pressurized hardware are not affected by the exceeded storage environment.

4.2.5 Factors of safety tables

Table 4-1: Factors of safety for unmanned missions

Application and load type	Proof factor (internal pressure only)	Burst Factor (internal pressure only)	FOSY (combined loads) [a]	FOSU (combined loads) [a]
PV: Internal pressure	1,25	1,5	1,1	1,25
PS: Internal pressure	1,1	1,25	1,1	1,25
MPC: lines and fittings with diameter < 38 mm: Internal pressure	1,5	4,0	1,1	1,25
MPC: lines and fittings with diameter ≥ 38 mm: Internal pressure	1,5	2,5	1,1	1,25

Application and load type	Proof factor (internal pressure only)	Burst Factor (internal pressure only)	FOSY (combined loads) [a]	FOSU (combined loads) [a]
other MPC (including batteries not meeting the pressure vessel definition): Internal pressure	1,5	2,5	1,1	1,25
COPC: Internal pressure	Values specified for PV			
MSPE: cryostats and batteries: Internal pressure	MSPE sealed container or hazardous fluid container	MSPE sealed container or hazardous fluid container	1,1	1,25
MSPE: heat pipes, loop heat pipes and capillary pumped loops: Internal pressure	1,5	2,5	1,1	1,25
MSPE: sealed containers: Internal pressure	1,25	1,5	1,1	1,25
MSPE: hazardous fluids container: Internal pressure	1,5	2,5	1,1	1,25
COSPE: Internal pressure	Values specified for PV			
Mechanical loads (including external pressure)	N/A	N/A	Values specified in ECSS-E-ST-32-10	Values specified in ECSS-E-ST-32-10

[a] No commonly agreed value within the space community can be provided for verification by analysis only.

NOTE Definition of load cases is addressed in clause 5.2.

Table 4-2: Factors of safety for human spaceflight

Application and load type	Proof factor (internal pressure only)	Burst Factor (internal pressure only)	FOSY (combined loads) [a]	FOSU (combined loads) [a]
PV: Internal pressure	1,25	1,5	1,1	1,4
MPS: Internal pressure	1,1	1,4	1,1	1,4
COPS & CPS: Internal pressure	1,2	1,4	1,1	1,4
Manned module: Internal pressure only	1,5	2,0	1,65	2,0

Application and load type	Proof factor (internal pressure only)	Burst Factor (internal pressure only)	FOSY (combined loads) [a]	FOSU (combined loads) [a]
Manned module: Internal pressure in combined load cases	N/A	N/A	1,1	1,4
MPC: lines and fittings with diameter < 38 mm: Internal pressure	1,5	4,0	1,1	1,4
MPC: lines and fittings with diameter ≥ 38 mm: Internal pressure	1,5	2,5	1,1	1,4
other MPC (including batteries not meeting the pressure vessel definition): Internal pressure	1,5	2,5	1,1	1,4
COPC: Internal pressure	Values specified for PV			
MSPE: cryostats and batteries: Internal pressure	MSPE sealed container or hazardous fluid container	MSPE sealed container or hazardous fluid container	1,1	1,4
MSPE: heat pipes, loop heat pipes and capillary pumped loops: Internal pressure	1,5	2,5	1,1	1,4
MSPE: sealed containers: Internal pressure	1,25	1,5	1,1	1,4
MSPE: hazardous fluids container: Internal pressure	1,5	2,5	1,1	1,4
COSPE: Internal pressure	Values specified for PV			
Mechanical loads (including external pressure)	N/A	N/A	Values specified in ECSS-E-ST-32-10	Values specified in ECSS-E-ST-32-10

Application and load type	Proof factor (internal pressure only)	Burst Factor (internal pressure only)	FOSY (combined loads) [a]	FOSU (combined loads) [a]
[a] No commonly agreed value within the space community can be provided for verification by analysis only NOTE 1 The FOSY of 1,1 for human spaceflight applications is reduced with respect to the value 1,25 currently defined in ECSS-E-ST-32-10C rev.2 Table 4-6. This is based on relevant requirements documents, like for example JSC 65828 Rev. B. It is likely that the FOSY value in ECSS-E-ST-32-10C for mechanical loads (including external pressure) of pressurized hardware will be updated similarly. Until then, tailoring of FOSY can be proposed. NOTE 2 Definition of load cases is addressed in clause 5.2.				

4.3 Pressure vessels

4.3.1 Factors of safety

ECSS-E-ST-32-02_0260035

a. The values in Table 4-1 and Table 4-2 shall be applied as minimum values of factors of safety for internal pressure of pressure vessels (PV).

NOTE to items a and b. Exceptions to the values provided in Table 4-1, Table 4-2 or ECSS-E-ST-32-10 are sometimes specified by the customer or granted with customer approval.
Examples of reasons for exceptions: ground/range safety rules, mitigation of concerns due to time dependent phenomena like creep and for composites stress rupture, human safety during the mission.

When this is the case for a burst factor, the following relations can be used for determination of the proof factor:

$j_{proof} = (1 + j_{burst}) / 2$ when $j_{burst} < 2,0$

$j_{proof} = 1,5$ when $j_{burst} > 2,0$

ECSS-E-ST-32-02_0260036

b. For loads different from internal pressure, minimum values of factors of safety for ‘pressurized hardware’ shall be applied in conformance with ECSS-E-ST-32-10.

NOTE Exceptions to the values provided in Table 4-1, Table 4-2 or ECSS-E-ST-32-10 are sometimes specified by the customer or granted with customer approval.
Examples of reasons for exceptions: ground/range safety rules, mitigation of concerns due to time dependent phenomena like creep and for

composites stress rupture, human safety during the mission.

When this is the case for a burst factor, the following relations can be used for determination of the proof factor:

$j_{proof} = (1 + j_{burst}) / 2$ when $j_{burst} < 2,0$

$j_{proof} = 1,5$ when $j_{burst} \geq 2,0$

ECSS-E-ST-32-02_0260428

<<deleted and replaced by new Table 4-1 and Table 4-2>>

4.3.2 Metallic pressure vessels

4.3.2.1 Development approach

ECSS-E-ST-32-02_0260037

a. Clause 5.2 on structural engineering shall be applied.

ECSS-E-ST-32-02_0260038

b. If specified, or relevant to comply with 4.2.3.1d, the LBB failure mode shall be demonstrated by analysis or test or both according to clause 5.3.

ECSS-E-ST-32-02_0260039

c. Except in the case specified in 4.3.2.1d, 'safe life item' demonstration shall be performed by analysis or test in conformance with ECSS-E-ST-32-01.

NOTE Relevant requirements can be found, for example, in clauses 8.2.1 (Pressurized hardware General) and 8.2.2 (Pressure vessels) of the ECSS-E-ST-32-01.

ECSS-E-ST-32-02_0260439

d. For pressure vessels with a non-hazardous LBB failure mode, the safe-life demonstration specified in 4.3.2.1c may be replaced by a fatigue life demonstration by analysis or test or both.

NOTE This can have an impact on the mission reliability. If a project is rated highly critical by the customer due to considerations other than safety, safe life to leakage verification of the metallic pressure vessel is sometimes requested instead of, or in addition to, LBB verification.
It is recommended that this agreement is achieved as early as possible, for example in the statement of work and associated baseline requirements, and then reflected in the Fracture Control Plan.

ECSS-E-ST-32-02_0260041

e. In the case specified in 4.3.2.1d, requirements for 'fatigue analysis' shall be applied in conformance with 5.2h and ECSS-E-ST-32, considering credible manufacturing imperfections and defects to the extent agreed between customer and supplier.

NOTE Requirement 5.2h specifies a scatter factor of 5 for fatigue analysis.

ECSS-E-ST-32-02_0260042

f. Qualification tests shall be conducted according to clause 4.3.2.2 to demonstrate the structural adequacy of the design.

ECSS-E-ST-32-02_0260043

g. For corrosion control and prevention, the requirements in ECSS-E-ST-32 shall apply.

NOTE ECSS-E-ST-32 refers to ECSS-Q-ST-70 and related standards.

ECSS-E-ST-32-02_0260044

h. For hydrogen embrittlement phenomena, requirements shall be applied in conformance with ECSS-E-ST-32-08.

ECSS-E-ST-32-02_0260045

i. For material selection, material design allowables and their characterisation, requirements shall be applied in conformance with ECSS-E-ST-32.

ECSS-E-ST-32-02_0260046

j. For 'process control', requirements shall be in conformance with ECSS-Q-ST-70.

ECSS-E-ST-32-02_0260047

k. Inspections shall be applied according to clause 5.7.

NOTE The development approach is illustrated in Figure 4-3.

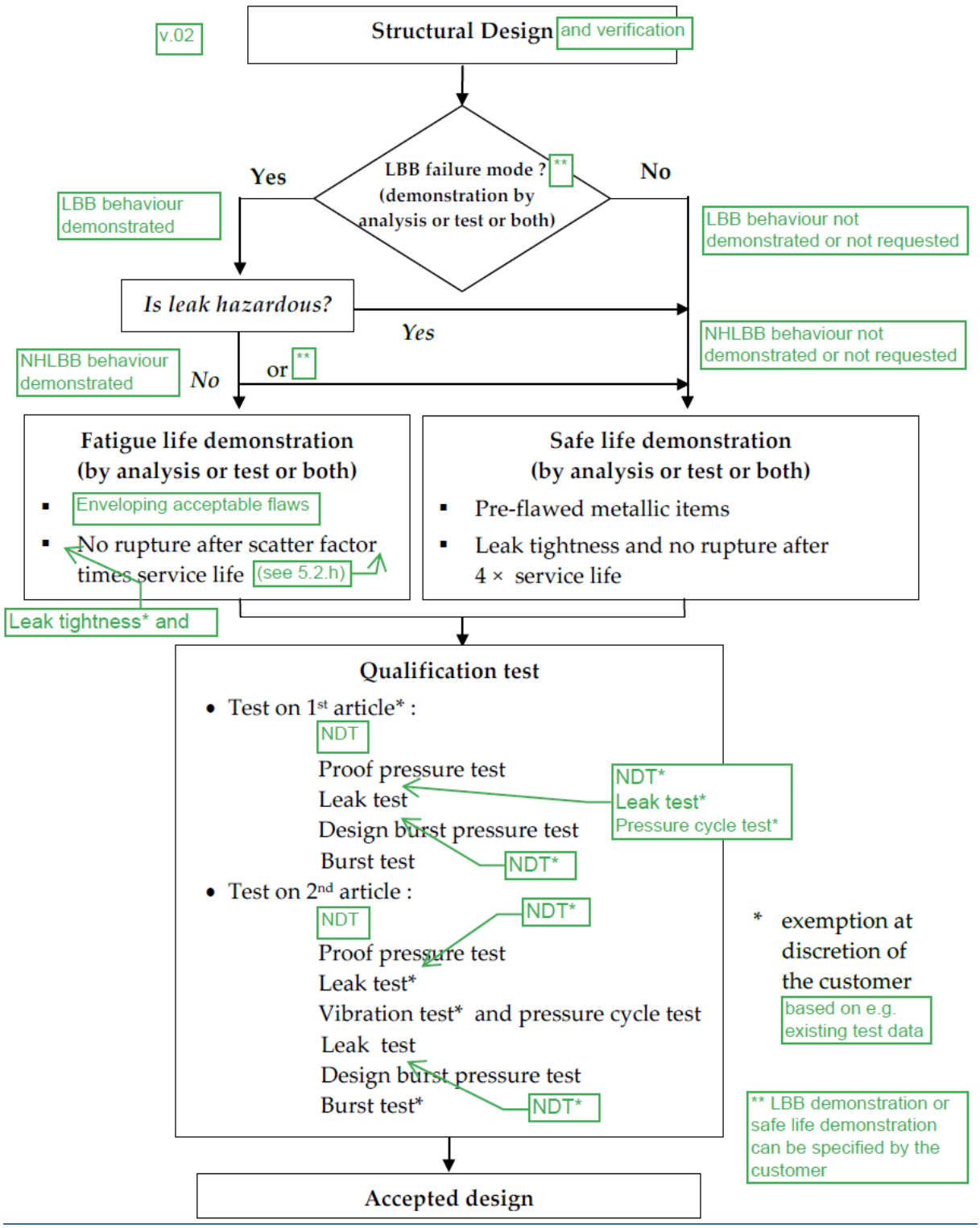

Figure 4-3: Development approach of MPV

4.3.2.2 Qualification tests

ECSS-E-ST-32-02_0260048

a. A first qualification test article shall be submitted to the following sequence of tests, or alternative sequence agreed between customer and supplier:

1. non-destructive testing (NDT);
2. proof pressure test;
3. leak test;
4. NDT;
5. pressure cycling test;
6. leak test;
7. design burst pressure test;
8. burst test.

NOTE This the standard sequence of tests defined in ECSS-E-ST-10-03. Examples of rationale for changes to this sequence are:

- Additional qualification test types (e.g. thermal) or inspection steps (e.g. before burst pressure testing);
- Identified risk that for the particular design the defined sequence can be either unconservative or unnecessarily conservative;
- Omission of test types based on successful heritage or testing of engineering model. Examples: pressure cycling test, burst test, NDT steps.

ECSS-E-ST-32-02_0260440

b. The first qualification test article specified in 4.3.2.2a may be deleted with customer approval.

NOTE Examples of rationale for deletion of a formal first qualification test article:

- Similarity with a qualified vessel giving confidence in the robustness of the design and manufacturing processes;
- Successful testing of a representative engineering model.
- Additional factors that can be considered: simplicity of the design, actual margins, heritage of the supplier.

ECSS-E-ST-32-02_0260050

c. A second qualification test article shall be submitted to the following sequence of tests, or alternative sequence agreed between customer and supplier:

1. NDT;
2. proof pressure test;
3. leak test;
4. NDT;
5. vibration tests;
6. pressure cycling test;
7. leak test;
8. design burst pressure test;
9. burst test.

NOTE This the standard sequence of tests defined in ECSS-E-ST-10-03. Examples of rationale for changes to this sequence are:

- Additional qualification test types (e.g. thermal) or inspection steps (e.g. before burst pressure testing);
- Identified risk that for the particular design the defined sequence can be either unconservative or unnecessarily conservative.
- Omission of test types based on successful heritage or testing of engineering model.

ECSS-E-ST-32-02_0260441

d. The leak test and NDT after proof pressure test, specified in 4.3.2.2c, and the final burst test specified in 4.3.2.2c may be deleted with customer approval.

ECSS-E-ST-32-02_0260442

e. When the vibration loads are enveloped by the other qualification tests, the vibration tests specified in 4.3.2.2c may be deleted with customer approval.

ECSS-E-ST-32-02_0260053

f. Clause 5.4 shall be applied to the qualification tests.

ECSS-E-ST-32-02_0260054

g. The need to apply external loads in combination with internal pressure during qualification testing shall be considered taking into account their relative magnitude, the fatigue and destabilizing effects of external loads.

NOTE This is considered, for example, for cases where locally or globally non-pressure loads are significant, and applicable yield or ultimate combined load cases are not covered by proof or burst testing, contradicting to some extent the characteristic that pressure loads are dominant, and where it is not acceptable to cover the difference by analysis, similarity, test on design detail, etc. In vibration testing the vibration loads, per axis, will actually apply the strength qualification factor of 1,25, but no factor, like FOSY or FOSU, on pressure.

ECSS-E-ST-32-02_0260055

h. If external cycling loads are applied, the load shall be cycled to limit for four times the predicted number of operating cycles of the most severe design condition.

NOTE Examples: Destabilizing load with constant minimum internal pressure or maximum additive load with a constant MDP.
The actual cycle life can be complex and is often replaced by a simplified test spectrum, of comparable severity, in the cycling test.

4.3.2.3 Acceptance tests

ECSS-E-ST-32-02_0260056

a. All hardware shall be submitted to the following sequence of tests, or alternative sequence agreed between customer and supplier:

1. initial NDT, in order to establish the initial condition of the hardware;
2. proof pressure test;
3. leak test;
4. final NDT.

NOTE For example:

- The NDT prior to proof test can be substituted for that of the manufacturing process.

ECSS-E-ST-32-02_0260057

b. Clause 5.5 shall be applied to the acceptance tests.

ECSS-E-ST-32-02_0260058

c. Final NDT shall be performed on the weld-joints of the MPV as a minimum.

4.3.3 COPV with metallic liner

4.3.3.1 Development approach

ECSS-E-ST-32-02_0260059

a. Clause 5.2 on structural engineering shall be applied.

ECSS-E-ST-32-02_0260060

b. A stiffness demonstration shall be performed by analysis and test.

ECSS-E-ST-32-02_0260061

c. A strength and stability demonstration shall be performed by analysis and test.

ECSS-E-ST-32-02_0260062

d. If specified, or relevant to comply with 4.3.3.1.d, the LBB failure mode shall be demonstrated by analysis or test or both according to clause 5.3.

ECSS-E-ST-32-02_0260063

e. For metallic COPV liners with a non-hazardous LBB failure mode, the safe-life demonstration specified in 4.3.3.1f may be replaced by a fatigue life demonstration by analysis or test or both in conformance with clause 5.2.h and ECSS-E-ST-32, considering credible manufacturing imperfections and defects to the extent agreed between customer and supplier .

NOTE This can have an impact on the mission reliability. If a project is rated highly critical by the customer due to considerations other than safety, safe life to leakage verification of the metallic liner is sometimes requested instead of, or in addition to, LBB verification.
It is recommended that this agreement is achieved as early as possible, for example in the statement of work and associated baseline requirements, and then reflected in the Fracture Control Plan.

ECSS-E-ST-32-02_0260064

f. Except in the case specified in 4.3.3.1e, 'safe life item' demonstration shall be performed for the metallic liner by analysis or test or both in conformance with ECSS-E-ST-32-01.

ECSS-E-ST-32-02_0260065

g. Fatigue-life demonstration shall be performed for the composite over-wrap by analysis or test or both in conformance with ECSS-E-ST-32.

ECSS-E-ST-32-02_0260066

h. Qualification tests shall be conducted according to clause 4.3.3.2 to demonstrate the structural adequacy of the design.

ECSS-E-ST-32-02_0260067

i. For corrosion control and prevention, the requirements in ECSS-E-ST-32 shall apply.

NOTE ECSS-E-ST-32 refers to ECSS-Q-ST-70 and related standards.

ECSS-E-ST-32-02_0260068

j. For hydrogen embrittlement phenomena, requirements shall be applied in conformance with ECSS-E-ST-32-08.

ECSS-E-ST-32-02_0260069

k. For material selection, material design allowables and their characterisation, requirements shall be applied in conformance with clause 5.6 and ECSS-E-ST-32.

ECSS-E-ST-32-02_0260070

l. For 'process control', requirements shall be in conformance with ECSS-Q-ST-70.

ECSS-E-ST-32-02_0260071

m. Inspections shall be applied according to clause 5.7.

NOTE The development approach is illustrated in Figure 4-4.

4.3.3.2 Qualification tests

ECSS-E-ST-32-02_0260072

a. A first qualification test article shall be submitted to the following sequence of tests, or alternative sequence agreed between customer and supplier:

1. non-destructive testing (NDT);
2. proof pressure test;
3. leak test;
4. NDT;
5. pressure cycling test;
6. leak test;
7. design burst pressure test;

8. burst test.

NOTE This the standard sequence of tests defined in ECSS-E-ST-10-03. Examples of rationale for changes to this sequence are:

- Additional qualification test types (e.g. thermal) or inspection steps (e.g. before burst pressure testing);
- Identified risk that for the particular design the defined sequence can be either unconservative or unnecessarily conservative
- Omission of test types based on successful heritage or testing of engineering model. Examples: pressure cycling test, burst test, NDT steps.

ECSS-E-ST-32-02_0260443

b. The first qualification test article specified in 4.3.3.2a may be deleted with customer approval.

NOTE Examples of rationale for deletion of a formal first qualification test article:

- Similarity with a qualified vessel giving confidence in the robustness of the design and manufacturing processes.
- Successful testing of a representative engineering model.
- Additional factors that can be considered: simplicity of the design, actual margins, heritage of the supplier.

ECSS-E-ST-32-02_0260074

c. A second qualification test article shall be submitted to the following sequence of tests, or alternative sequence agreed between customer and supplier:

1. NDT;
2. proof pressure test;
3. leak test;
4. NDT;
5. vibration tests;
6. pressure cycling test;
7. leak test;
8. design burst pressure test;
9. burst test.

NOTE This the standard sequence of tests defined in ECSS-E-ST-10-03. Examples of rationale for changes to this sequence are:

- Additional qualification test types (e.g. thermal) or inspection steps (e.g. before burst pressure testing);
- Identified risk that for the particular design the defined sequence can be either unconservative or unnecessarily conservative.
- Omission of test types based on successful heritage or testing of engineering model.

ECSS-E-ST-32-02_0260444

d. The leak test and NDT after proof pressure test specified in 4.3.3.2c, and the final burst test specified in4.3.3.2c may be deleted with customer approval.

ECSS-E-ST-32-02_0260445

e. When the vibration loads are enveloped by the other qualification tests, the vibration tests specified in 4.3.3.2c may be deleted with customer approval.

ECSS-E-ST-32-02_0260077

f. NDT operations shall be applied to the over-wrap, in addition to NDT on the liner.

ECSS-E-ST-32-02_0260078

g. Clause 5.4 shall be applied to the qualification tests.

ECSS-E-ST-32-02_0260079

h. The need to apply external loads in combination with internal pressure during qualification testing shall be considered taking into account their relative magnitude, the fatigue and destabilizing effects of external loads.

NOTE This is considered, for example, for cases where locally or globally non-pressure loads are significant, and applicable yield or ultimate combined load cases are not covered by proof or burst testing, contradicting to some extent the characteristic that pressure loads are dominant, and where it is not acceptable to cover the difference by analysis, similarity, test on design detail, etc. In vibration testing the vibration loads, per axis, will actually apply the strength qualification factor of 1,25, but no factor, like FOSY or FOSU, on pressure.

ECSS-E-ST-32-02_0260080

i. If external cycling loads are applied, the load shall be cycled to limit for four times the predicted number of operating cycles of the most severe design condition.

NOTE For example: destabilizing load with constant minimum internal pressure or maximum additive load with a constant MDP.
The actual cycle life can be complex and is often replaced by a simplified test spectrum, of comparable severity, in the cycling test.

4.3.3.3 Acceptance tests

ECSS-E-ST-32-02_0260081

a. All hardware shall be submitted to the following sequence of tests, or alternative sequence agreed between customer and supplier:

1. initial NDT, in order to establish the initial condition of the hardware;
2. proof pressure test;
3. leak test;
4. final NDT.

NOTE For example:

- The NDT prior to proof test can be substituted for that of the manufacturing process.
- Proof test monitoring by acoustic emission is acceptable for composite items (i.e. not for the liner) instead of post testing NDT, with customer approval. Detailed acoustic emission procedures, with proven health monitoring capability, are agreed per NDT plan, in line with the general requirements of clauses 5 and 9 of the ECSS-Q-ST-70-15.

ECSS-E-ST-32-02_0260082

b. Initial NDT operations shall be applied to the over-wrap, in addition to NDT on the liner.

ECSS-E-ST-32-02_0260083

c. Clause 5.5 shall be applied to the acceptance tests.

ECSS-E-ST-32-02_0260084

d. Final NDT shall be performed on the over-wrap of the COPV as a minimum.

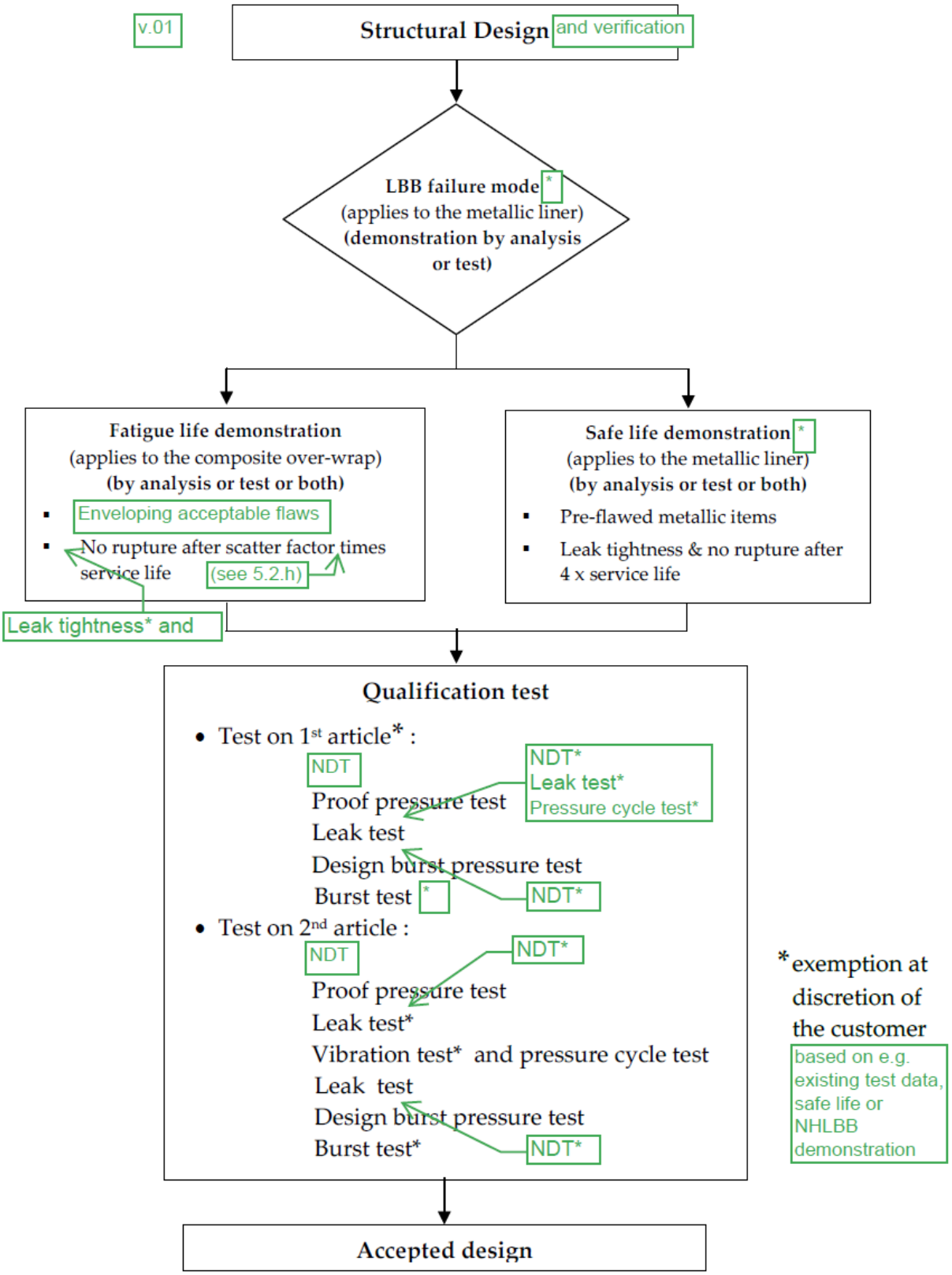

Figure 4-4: Development approach of COPV with metallic liner
(relevant also for COPC and COSPE with metallic liner)

4.3.4 COPV with homogeneous non metallic liner and CPV

4.3.4.1 Development approach

ECSS-E-ST-32-02_0260085

a. Clause 5.2 on structural engineering shall be applied.

ECSS-E-ST-32-02_0260086

b. A stiffness demonstration shall be performed by analysis and test.

ECSS-E-ST-32-02_0260087

c. A strength and stability demonstration shall be performed by analysis and test.

ECSS-E-ST-32-02_0260088

d. The LBB failure mode shall be demonstrated using a method agreed with the customer.

NOTE Experience with non-metallic lined COPV and CPV is limited, and LBB failure mode demonstration according to 5.3 can be difficult or not relevant (see also e and f below). No definite requirements are therefore provided in this standard on whether and how to apply clause 5.3, and specifically 5.3.4 (Demonstration of LBB by test using full-scale article).

ECSS-E-ST-32-02_0260089

e. The liner of the COPV shall exhibit a LBB failure mode.

NOTE The fulfilment of this requirement is sometimes possible without LBB analysis or test per 5.3, for liners that do not experience significant load when compared to the overwrap. Example: thermoplastic liner, see e.g. AIAA G-082.

ECSS-E-ST-32-02_0260090

f. The CPV shall exhibit a LBB failure mode, if requested by the customer.

NOTE Experience with CPV is limited, and LBB demonstration can be difficult or not relevant. No definite guidance is therefore provided in this standard.

ECSS-E-ST-32-02_0260446

g. When the non-metallic liner of the COPV remains in compression up to MDP and surface flaws do not propagate during the LBB test, the flaws pre-fabricated in the liner of the LBB full-scale specimen may be through cracks.

ECSS-E-ST-32-02_0260092

h. 'Safe life item' demonstration of the liner shall be performed in conformance with ECSS-E-ST-32-01:

1. by test for non-metallic items;
2. by analysis or test or both for metallic items (e.g. metallic bosses).

ECSS-E-ST-32-02_0260093

i. Qualification tests shall be conducted according to clause 4.3.4.2 to demonstrate the structural adequacy of the design.

ECSS-E-ST-32-02_0260094

j. For corrosion control and prevention, the requirements in ECSS-E-ST-32 shall apply.

NOTE ECSS-E-ST-32 refers to ECSS-Q-ST-70 and related standards.

ECSS-E-ST-32-02_0260095

k. For hydrogen embrittlement phenomena, requirements shall be applied in conformance with ECSS-E-ST-32-08.

ECSS-E-ST-32-02_0260096

l. For material selection, material design allowables and their characterisation, requirements shall be applied in conformance with clause 5.6 and ECSS-E-ST-32.

ECSS-E-ST-32-02_0260097

m. For 'process control', requirements shall be in conformance with ECSS-Q-ST-70.

ECSS-E-ST-32-02_0260098

n. Inspections shall be applied according to clause 5.7.

NOTE The development approach is illustrated in Figure 4-5.

o. Fatigue-life demonstration shall be performed for the composite over-wrap by analysis or test or both in conformance with ECSS-E-ST-32.

4.3.4.2 Qualification tests

ECSS-E-ST-32-02_0260099

a. A first qualification test article shall be submitted to the following sequence of tests, or alternative sequence agreed between customer and supplier:

1. non-destructive testing (NDT);
2. proof pressure test;
3. leak test;
4. NDT;
5. pressure cycling test;
6. leak test;
7. design burst pressure test;
8. burst test.

NOTE This the standard sequence of tests defined in ECSS-E-ST-10-03. Examples of rationale for changes to this sequence are:

- Additional qualification test types (e.g. thermal) or inspection steps (e.g. before burst pressure testing);
- Identified risk that for the particular design the defined sequence can be either unconservative or unnecessarily conservative.
- Omission of test types based on successful heritage or testing of engineering model. Examples: pressure cycling test, burst test, NDT steps.

ECSS-E-ST-32-02_0260447

b. The first qualification test article specified in 4.3.4.2a may be deleted with customer approval.

NOTE Examples of rationale for deletion of a formal first qualification test article:

- Similarity with a qualified vessel giving confidence in the robustness of the design and manufacturing processes.
- Successful testing of a representative engineering model.
- Additional factors that can be considered: simplicity of the design, actual margins, heritage of the supplier.

ECSS-E-ST-32-02_0260101

c. A second qualification test article shall be submitted to the following sequence of tests, or alternative sequence agreed between customer and supplier:

1. NDT;
2. proof pressure test;
3. leak test;
4. NDT;
5. vibration tests;
6. pressure cycling test;
7. leak test;
8. design burst pressure test;
9. burst test.

NOTE This the standard sequence of tests defined in ECSS-E-ST-10-03. Examples of rationale for changes to this sequence are:

- Additional qualification test types (e.g. thermal) or inspection steps (e.g. before burst pressure testing).
- Identified risk that for the particular design the defined sequence can be either unconservative or unnecessarily conservative.
- Omission of test types based on successful heritage or testing of engineering model.

ECSS-E-ST-32-02_0260448

d. The leak test and NDT after proof pressure test specified in 4.3.4.2c, and the final burst test specified in 4.3.4.2c may be deleted with customer approval.

ECSS-E-ST-32-02_0260449

e. When the vibration loads are enveloped by the other qualification tests, the vibration tests specified in 4.3.4.2c may be deleted with customer approval.

ECSS-E-ST-32-02_0260104

f. For COPV, NDT operations shall be applied to the over-wrap, in addition to NDT on the liner.

ECSS-E-ST-32-02_0260105

g. For CPV, NDT operations shall be applied to the composite wall.

ECSS-E-ST-32-02_0260106

h. Clause 5.4 shall be applied to the qualification tests.

ECSS-E-ST-32-02_0260107

i. The need to apply external loads in combination with internal pressure during qualification testing shall be considered taking into account their relative magnitude, the fatigue and destabilizing effects of external loads.

NOTE This is considered, for example, for cases where locally or globally non-pressure loads are significant, and applicable yield or ultimate combined load cases are not covered by proof or burst testing, contradicting to some extent the characteristic that pressure loads are dominant, and where it is not acceptable to cover the difference by analysis, similarity, test on design detail, etc. In vibration testing the vibration loads, per axis, will actually apply the strength qualification factor of 1,25, but no factor, like FOSY or FOSU, on pressure.

ECSS-E-ST-32-02_0260108

j. If external cycling loads are applied, the load shall be cycled to limit for four times the predicted number of operating cycles of the most severe design condition.

NOTE Examples: Destabilizing load with constant minimum internal pressure or maximum additive load with a constant MDP.
The actual cycle life can be complex and is often replaced by a simplified test spectrum, of comparable severity, in the cycling test.

4.3.4.3 Acceptance tests

ECSS-E-ST-32-02_0260109

a. All hardware shall be submitted to the following sequence of tests, or alternative sequence agreed between customer and supplier:

1. initial NDT, in order to establish the initial condition of the hardware;
2. proof pressure test;
3. leak test;
4. final NDT.

NOTE For example:

- The NDT prior to proof test can be substituted for that of the manufacturing process.

- Proof test monitoring by acoustic emission is acceptable for composite items instead of post testing NDT, with customer approval. Detailed acoustic emission procedures, with proven health monitoring capability, are agreed per NDT plan, in line with the general requirements of clauses 5 and 9 of the ECSS-Q-ST-70-15.

ECSS-E-ST-32-02_0260110

b. For COPV, initial NDT operations shall be applied to the over-wrap, in addition to NDT on the liner.

ECSS-E-ST-32-02_0260111

c. For CPV, NDT operations shall be applied to the composite wall as a minimum.

ECSS-E-ST-32-02_0260112

d. Clause 5.5 shall be applied to the acceptance tests.

ECSS-E-ST-32-02_0260113

e. Final NDT shall be performed on the over-wrap of the COPV as a minimum.

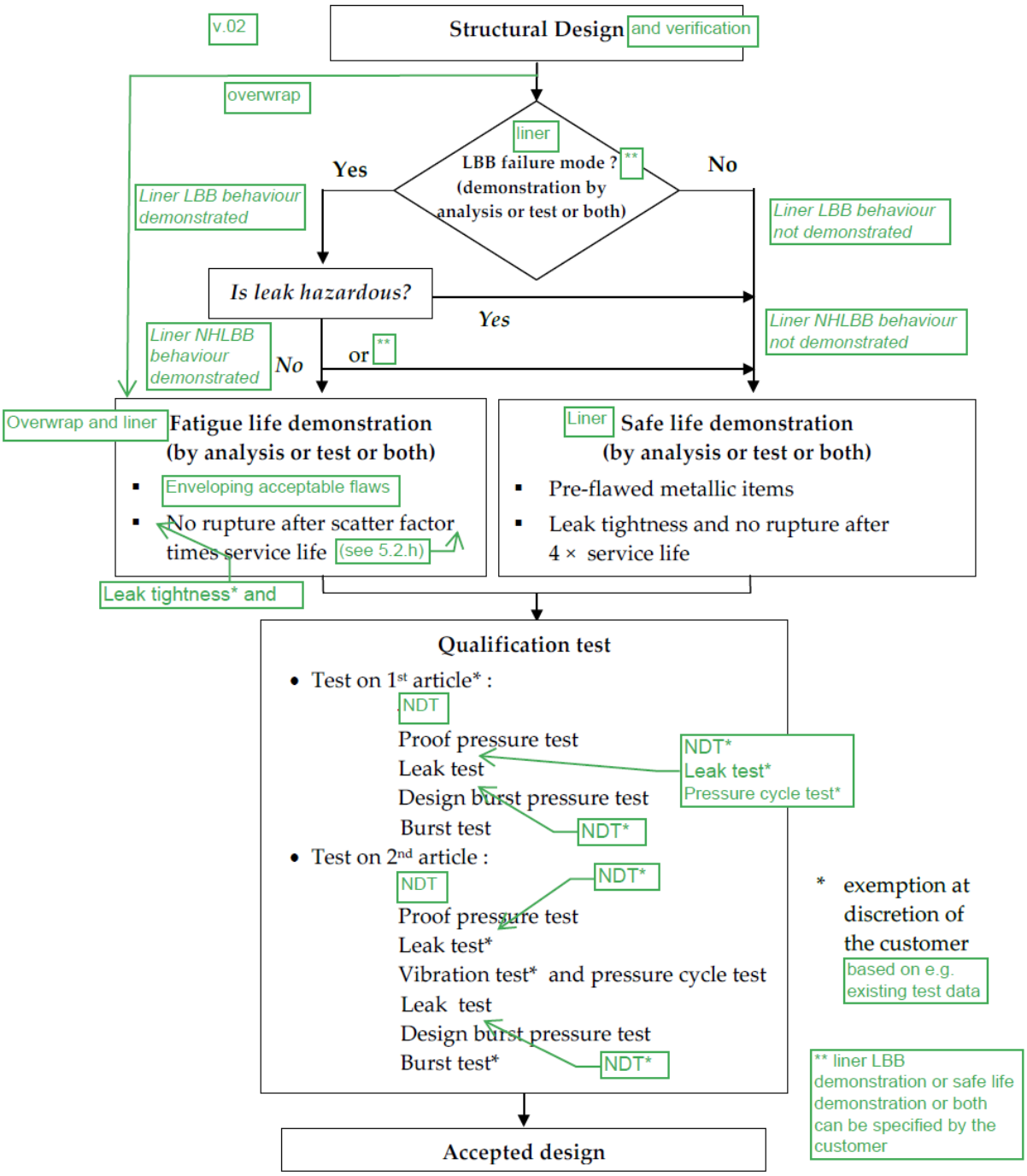

Figure 4-5: Development approach of COPV with homogeneous non metallic liner and CPV

(Relevant also for COPC and COSPE with homogeneous non-metallic liner)

4.4 Pressurized structures

4.4.1 Factors of safety

ECSS-E-ST-32-02_0260114

a. The values in Table 4-1 and Table 4-2 shall be applied as minimum values of factors of safety for internal pressure of pressurized structures (PS) and manned modules.

NOTE Exceptions to the values provided in Table 4-1, Table 4-2 or ECSS-E-ST-32-10 are sometimes specified by the customer or granted with customer approval.
Examples of reasons for exceptions: ground/rangeC safety rules, mitigation of concerns due to time dependent phenomena like creep and for composites stress rupture, human safety during the mission.

ECSS-E-ST-32-02_0260115

b. The values specified in ECSS-E-ST-32-10 for 'pressurized hardware' shall be applied as minimum values of factors of safety for loads different from internal pressure.

NOTE Exceptions to the values provided in Table 4-1, Table 4-2 or ECSS-E-ST-32-10 are sometimes specified by the customer or granted with customer approval.
Examples of reasons for exceptions: ground/range safety rules, mitigation of concerns due to time dependent phenomena like creep and for composites stress rupture, human safety during the mission.

ECSS-E-ST-32-02_0260116

c. <<deleted (covered by clause 5.2)>>

ECSS-E-ST-32-02_0260117

d. <<deleted (to be addressed as tailoring)>>

ECSS-E-ST-32-02_0260118

e. <<deleted (covered by FOS tables)>>

ECSS-E-ST-32-02_0260119

f. <<deleted (covered by FOS tables)>>

ECSS-E-ST-32-02_0260429

ECSS-E-ST-32-02_0260430

4.4.2 Metallic pressurized structures

4.4.2.1 Development approach

ECSS-E-ST-32-02_0260120

a. Clause 5.2 on structural engineering shall be applied.

NOTE Pressurized structures are both pressurized hardware and structures. It is specifically emphasized here that it is important to ensure that both the specific pressurized hardware requirements of this standard and the structural requirements of the other ECSS structural standards are met.
Solid propellant motor cases are not covered by this standard, unless specified or agreed otherwise.

ECSS-E-ST-32-02_0260121

b. If specified, or relevant to comply with 4.4.2.1.d, the LBB failure mode shall be demonstrated by analysis or test or both according to clause 5.3.

ECSS-E-ST-32-02_0260122

c. Except in the case specified in 4.4.2.1d, 'safe life item' demonstration shall be performed by analysis or test or both in conformance with ECSS-E-ST-32-01.

ECSS-E-ST-32-02_0260450

d. For pressurized structures with a non-hazardous LBB failure mode, the safe-life demonstration specified in 4.4.2.1c may be replaced by a fatigue life demonstration by analysis or test or both, with customer approval.

NOTE This can have an impact on the mission reliability.
NHLBB demonstration, either full or partial, can be challenging for pressurized structures, because pressure is most likely not the dominant loading type.
Also, if a project is rated highly critical by the customer due to considerations other than safety, safe life to leakage verification of the metallic pressurized structure is sometimes requested instead of, or in addition to, LBB verification. It is recommended that this agreement is achieved as early as possible, for example in the statement of

work and associated baseline requirements, and then reflected in the Fracture Control Plan.

ECSS-E-ST-32-02_0260124

e. In the case specified in 4.4.2.1d, requirements for 'fatigue analysis' shall be applied in conformance with clause 5.2.h and ECSS-E-ST-32, considering credible manufacturing imperfections and defects to the extent agreed between customer and supplier.

ECSS-E-ST-32-02_0260125

f. Qualification tests shall be conducted according to clause 4.4.2.2 to demonstrate the structural adequacy of the design.

ECSS-E-ST-32-02_0260126

g. For corrosion control and prevention,, the requirements in ECSS-E-ST-32 shall apply.

NOTE ECSS-E-ST-32 refers to ECSS-Q-ST-70 and related standards.

ECSS-E-ST-32-02_0260127

h. For hydrogen embrittlement phenomena, requirements shall be applied in conformance with ECSS-E-ST-32-08.

ECSS-E-ST-32-02_0260128

i. For material selection, material design allowables and their characterisation, requirements shall be applied in conformance with ECSS-E-ST-32.

ECSS-E-ST-32-02_0260129

j. For 'process control', requirements shall be in conformance with ECSS-Q-ST-70.

ECSS-E-ST-32-02_0260130

k. Inspections shall be applied according to clause 5.7.

NOTE The development approach is illustrated in Figure 4-6.

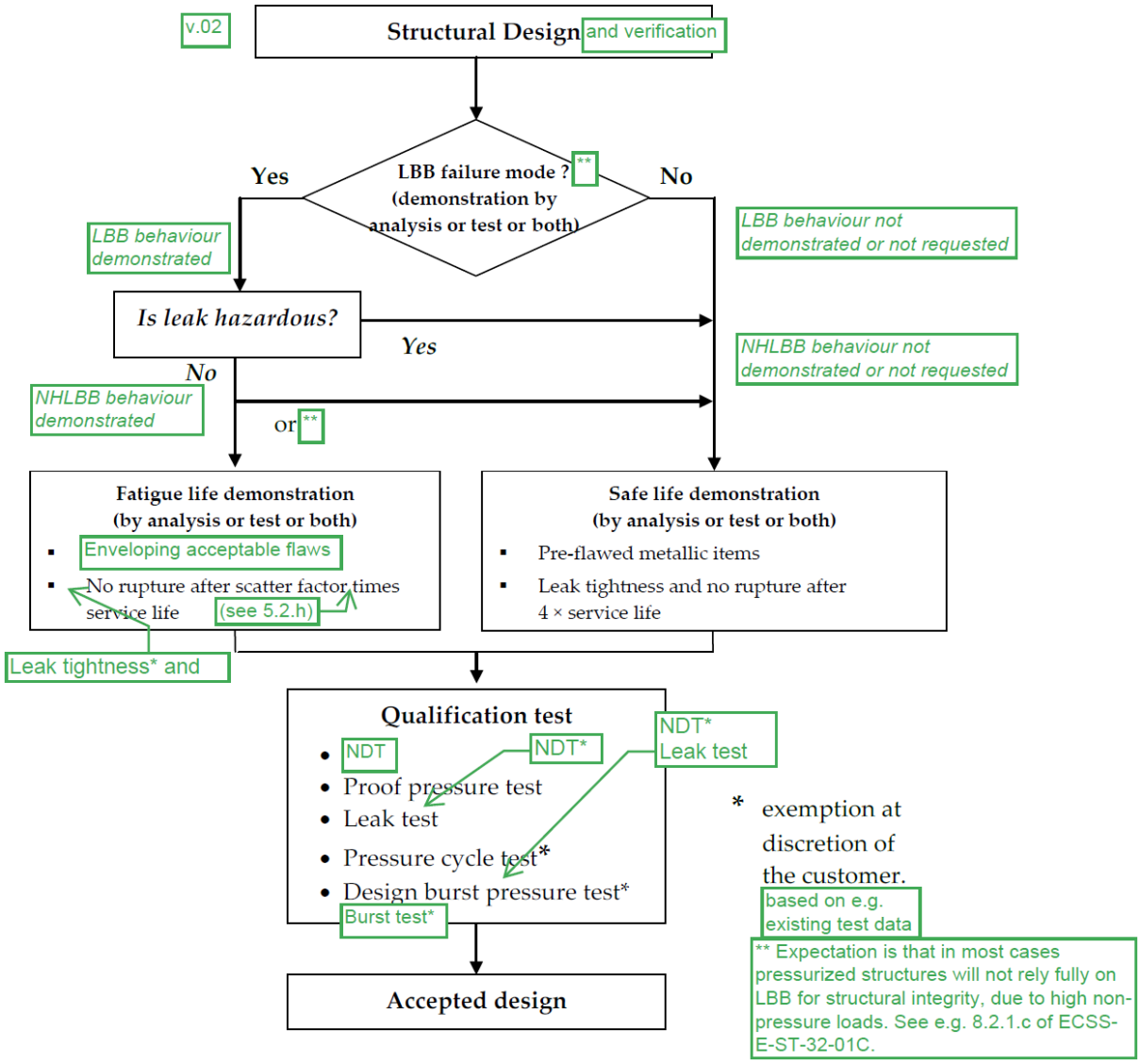

Figure 4-6: Development approach of MPS

4.4.2.2 Qualification tests

ECSS-E-ST-32-02_0260131

a. The qualification test article shall be submitted to the following sequence of tests, or alternative sequence agreed between customer and supplier:

1. NDT;
2. proof pressure test;
3. leak test;
4. NDT;
5. pressure cycling test;
6. leak test;

7. design burst pressure test;

8. burst test.

NOTE This is based on the standard sequence of tests defined in ECSS-E-ST-10-03. Examples of rationale for changes to this sequence are:

- Additional qualification test types (e.g. thermal) or inspection steps (e.g. before burst pressure testing);
- Identified risk that for the particular design the defined sequence can be either unconservative or unnecessarily conservative;
- Omission of test types based on successful heritage or testing of engineering model. Examples: pressure cycling test, burst test, NDT steps.

ECSS-E-ST-32-02_0260451

b. <<deleted: where relevant deletion of qualification tests can be addressed in 4.4.2.2a>>

ECSS-E-ST-32-02_0260133

c. Clause 5.4 shall be applied to the qualification tests.

ECSS-E-ST-32-02_0260134

d. The need to apply external loads in combination with internal pressure during qualification testing shall be considered taking into account their relative magnitude, fatigue and destabilizing effects of external loads, and agreed with the customer.

NOTE For a pressurized structure external loads, including thermo-mechanical loads, are normally significant in magnitude and therefore likely to be relevant for the qualification testing. In some cases the difference can be covered by analysis or similarity.

ECSS-E-ST-32-02_0260135

e. If external cycling loads are applied, the load shall be cycled to limit for four times the predicted number of operating cycles of the most severe design condition.

NOTE Examples: Destabilizing load with constant minimum internal pressure or maximum additive load with a constant MDP.
The actual cycle life can be complex and is often replaced by a simplified test spectrum, of comparable severity, in the cycling test.

4.4.2.3 Acceptance tests

ECSS-E-ST-32-02_0260136

a. All hardware shall be submitted to the following sequence of tests, or alternative sequence agreed between customer and supplier:

1. initial NDT, in order to establish the initial condition of the hardware;
2. proof pressure test;
3. leak test;
4. final NDT.

NOTE The NDT prior to proof test can be substituted for that of the manufacturing process.

ECSS-E-ST-32-02_0260137

b. Clause 5.5 shall be applied to the acceptance tests.

ECSS-E-ST-32-02_0260138

c. Final NDT shall be performed on the weld-joints of the MPS as a minimum.

4.4.3 COPS with metallic liner

4.4.3.1 Development approach

ECSS-E-ST-32-02_0260139

a. Clause 5.2 on structural engineering shall be applied.

NOTE Pressurized structures are both pressurized hardware and structures. It is specifically emphasized here that it is important to ensure that both the specific pressurized hardware requirements of this standard and the structural requirements of the other ECSS structural standards are met.
Solid propellant motor cases are not covered by this standard, unless specified or agreed otherwise.

ECSS-E-ST-32-02_0260140

b. A stiffness demonstration shall be performed by analysis and test.

ECSS-E-ST-32-02_0260141

c. A strength and stability demonstration shall be performed by analysis and test.

ECSS-E-ST-32-02_0260142

d. If specified, or relevant to comply with 4.4.3.1.f, the LBB failure mode shall be demonstrated by analysis or test or both according to clause 5.3.

ECSS-E-ST-32-02_0260143

e. The metallic liner of the COPS shall exhibit a LBB failure mode.

ECSS-E-ST-32-02_0260144

f. 'Safe life item' demonstration shall be performed for the both the metallic liner and the composite overwrap by analysis or test or both in conformance with ECSS-E-ST-32-01, in accordance with clause 8.4 for composite items, unless agreed otherwise by the customer.

NOTE For fracture control of the composite overwrap, refer to 8.4 (Composite, bonded and sandwich structures) or 11.2.2.5 (Safe life composite, bonded and sandwich; for non human spaceflight applications) of ECSS-E-ST-32-01C. Note that 8.2.3.1.c of ECSS-E-ST-32-01C specifies that pressurized structures which have composite overwrap are not implemented for human spaceflight missions without approval of the customer.

ECSS-E-ST-32-02_0260145

g. Fatigue-life demonstration shall be performed for the composite over-wrap by analysis or test or both in conformance with ECSS-E-ST-32.

ECSS-E-ST-32-02_0260146

h. Qualification tests shall be conducted in conformance with clause 4.4.3.2 to demonstrate the structural adequacy of the design.

ECSS-E-ST-32-02_0260147

i. For corrosion control and prevention, the requirements in ECSS-E-ST-32 shall apply.

NOTE ECSS-E-ST-32 refers to ECSS-Q-ST-70 and related standards.

ECSS-E-ST-32-02_0260148

j. For hydrogen embrittlement phenomena, requirements shall be applied in conformance with ECSS-E-ST-32-08.

ECSS-E-ST-32-02_0260149

k. For material selection, material design allowables and their characterisation, requirements shall be applied in conformance with clause 5.6 and ECSS-E-ST-32.

ECSS-E-ST-32-02_0260150

l. For 'process control', requirements shall be in conformance with ECSS-Q-ST-70.

ECSS-E-ST-32-02_0260151

m. Inspections shall be applied according to clause 5.7.

NOTE The development approach is illustrated in Figure 4-7.

4.4.3.2 Qualification tests

ECSS-E-ST-32-02_0260152

a. The qualification test article shall be submitted to the following sequence of tests, or alternative sequence agreed between customer and supplier:

1. NDT;
2. proof pressure test;
3. leak test;
4. NDT;
5. pressure cycling test;
6. leak test;
7. design burst pressure test.

NOTE This is based on the standard sequence of tests defined in ECSS-E-ST-10-03. Examples of rationale for changes to this sequence are:

- Additional qualification test types (e.g. thermal) or inspection steps (e.g. before burst pressure testing);
- Identified risk that for the particular design the defined sequence can be either unconservative or unnecessarily conservative;
- Omission of test types based on successful heritage or testing of engineering model. Examples: pressure cycling test, burst test, NDT steps.

ECSS-E-ST-32-02_0260452

b. <<deleted: where relevant it can be addressed in 4.4.3.2a>>

ECSS-E-ST-32-02_0260154

c. NDT operations shall be applied to the over-wrap, in addition to NDT on the liner.

ECSS-E-ST-32-02_0260155

d. Clause 5.4 shall be applied to the qualification tests.

ECSS-E-ST-32-02_0260156

e. The need to apply external loads in combination with internal pressure during qualification testing shall be considered taking into account their relative magnitude, fatigue and destabilizing effects of external loads, and agreed with the customer.

NOTE For a pressurized structure external loads, including thermo-mechanical loads, are normally significant in magnitude and therefore likely to be relevant for the qualification testing. In some cases the difference can be covered by analysis or similarity.

ECSS-E-ST-32-02_0260157

f. If external cycling loads are applied, the load shall be cycled to limit for four times the predicted number of operating cycles of the most severe design condition.

NOTE Example: Destabilizing load with constant minimum internal pressure or maximum additive load with a constant MDP.
The actual cycle life can be complex and is often replaced by a simplified test spectrum, of comparable severity, in the cycling test.

4.4.3.3 Acceptance tests

ECSS-E-ST-32-02_0260158

a. All hardware shall be submitted to the following sequence of tests, or alternative sequence agreed between customer and supplier:

1. initial NDT, in order to establish the initial condition of the hardware;
2. proof pressure test;
3. leak test;
4. final NDT.

NOTE For example:

- The NDT prior to proof test can be substituted for that of the manufacturing process.

- Proof test monitoring by acoustic emission is acceptable for composite items instead of post testing NDT, with customer approval. Detailed acoustic emission procedures, with proven health monitoring capability, are agreed per NDT plan, in line with the general requirements of clauses 5 and 9 of the ECSS-Q-ST-70-15C.

ECSS-E-ST-32-02_0260159

b. Initial NDT operations shall be applied to the over-wrap, in addition to NDT on the liner.

ECSS-E-ST-32-02_0260160

c. Clause 5.5 shall be applied to the acceptance tests.

ECSS-E-ST-32-02_0260161

d. Final NDT shall be performed on the over-wrap of the COPS as a minimum.

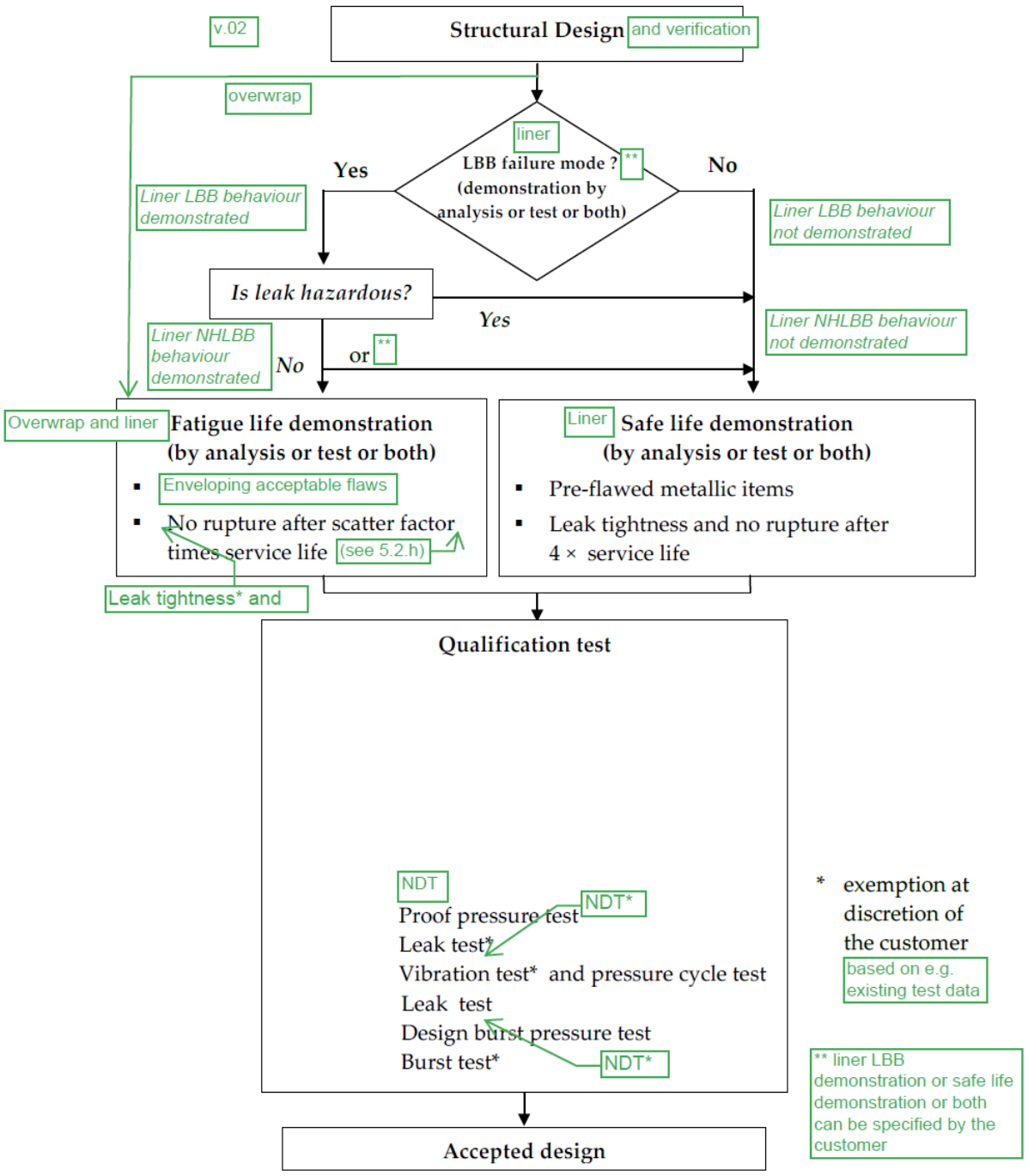

Figure 4-7: Development approach of COPS with metallic liner

4.4.4 COPS with homogeneous non metallic liner and CPS

4.4.4.1 Development approach

ECSS-E-ST-32-02_0260162

a. Clause 5.2 on structural engineering shall be applied.

NOTE Pressurized structures are both pressurized hardware and structures. It is specifically emphasized here that it is important to ensure that both the specific pressurized hardware requirements of this standard and the structural requirements of the other ECSS structural standards are met.
Solid propellant motor cases are not covered by this standard, unless specified or agreed otherwise.

ECSS-E-ST-32-02_0260163

b. A stiffness demonstration shall be performed by analysis and test.

ECSS-E-ST-32-02_0260164

c. A strength and stability demonstration shall be performed by analysis and test.

ECSS-E-ST-32-02_0260165

d. The LBB failure mode shall be demonstrated by test using a method agreed with the customer.

NOTE Experience with non-metallic lined COPS and CPS is limited, and LBB failure mode demonstration according to 5.3 can be difficult or not relevant (see also e and f below). No definite requirements are therefore provided in this standard on whether and how to apply clause 5.3, and specifically 5.3.4 (Demonstration of LBB by test using full-scale article).

ECSS-E-ST-32-02_0260166

e. The liner of the COPS shall exhibit a LBB failure mode.

NOTE The fulfilment of this requirement is sometimes possible without LBB analysis or test per 5.3, for liners that do not experience significant load when compared to the overwrap. Example: thermoplastic liner, see e.g. AIAA G-082.

ECSS-E-ST-32-02_0260167

f. The CPS shall exhibit a LBB failure mode, if requested by the customer.

NOTE Experience with CPS is limited, and LBB demonstration can be difficult or not relevant. No definite guidance is therefore provided in this standard.

ECSS-E-ST-32-02_0260453

g. When the non-metallic liner of the COPS remains in compression up to MDP and surface flaws do not propagate during the LBB test, the flaws pre-fabricated in the liner of the LBB full-scale specimen may be through cracks.

ECSS-E-ST-32-02_0260169

h. 'Safe life item' demonstration shall be performed for the both the metallic liner and the composite overwrap by analysis or test or both in conformance with ECSS-E-ST-32-01, in accordance with clause 8.4 for composite items, unless agreed otherwise by the customer.

NOTE For fracture control of the composite overwrap, refer to 8.4 (Composite, bonded and sandwich structures) or 11.2.2.5 (Safe life composite, bonded and sandwich; for non human spaceflight applications) of ECSS-E-ST-32-01C. Note that 8.2.3.1.c of ECSS-E-ST-32-01C specifies that pressurized structures which have composite overwrap are not implemented for human spaceflight missions without approval of the customer.

ECSS-E-ST-32-02_0260170

i. Qualification tests shall be conducted according to clause 4.4.4.2 to demonstrate the structural adequacy of the design.

ECSS-E-ST-32-02_0260171

j. For corrosion control and prevention, the requirements in ECSS-E-ST-32 shall apply.

NOTE ECSS-E-ST-32 refers to ECSS-Q-ST-70 and related standards.

ECSS-E-ST-32-02_0260172

k. For hydrogen embrittlement phenomena, requirements shall be applied in conformance with ECSS-E-ST-32-08.

ECSS-E-ST-32-02_0260173

l. For materials selection, material design allowables and their characterisation, requirements shall be applied in accordance with clause 5.6 and ECSS-E-ST-32.

ECSS-E-ST-32-02_0260174

m. For 'process control', requirements shall be in conformance with ECSS-Q-ST-70.

ECSS-E-ST-32-02_0260175

n. Inspections shall be applied according to clause 5.7.

NOTE The development approach is illustrated in Figure 4-8.

o. Fatigue-life demonstration shall be performed for the composite over-wrap by analysis or test or both in conformance with ECSS-E-ST-32.

4.4.4.2 Qualification tests

ECSS-E-ST-32-02_0260176

a. The qualification test article shall be submitted to the following sequence of tests, or alternative sequence agreed between customer and supplier:

1. NDT;
2. proof pressure test;
3. leak test;
4. NDT;
5. pressure cycling test;
6. leak test;
7. design burst pressure test.

NOTE This is based on the standard sequence of tests defined in ECSS-E-ST-10-03. Examples of rationale for changes to this sequence are:

- Additional qualification test types (e.g. thermal) or inspection steps (e.g. before burst pressure testing);
- Identified risk that for the particular design the defined sequence can be either unconservative or unnecessarily conservative;
- Omission of test types based on successful heritage or testing of engineering model. Examples: pressure cycling test, burst test, NDT steps.

ECSS-E-ST-32-02_0260177

b. For COPS, NDT operations shall be applied to the over-wrap, in addition to NDT on the liner.

ECSS-E-ST-32-02_0260178

c. For CPS, NDT operations shall be applied to the composite wall.

ECSS-E-ST-32-02_0260179

d. Clause 5.4 shall be applied to the qualification tests.

ECSS-E-ST-32-02_0260180

e. The need to apply external loads in combination with internal pressure during qualification testing shall be considered taking into account their relative magnitude, fatigue and destabilizing effects of external loads, and agreed with the customer.

NOTE For a pressurized structure external loads, including thermo-mechanical loads, are normally significant in magnitude and therefore likely to be relevant for the qualification testing. In some cases the difference can be covered by analysis or similarity.

ECSS-E-ST-32-02_0260181

f. If external cycling loads are applied, the load shall be cycled to limit for four times the predicted number of operating cycles of the most severe design condition.

NOTE Examples: Destabilizing load with constant minimum internal pressure or maximum additive load with a constant MDP.
The actual cycle life can be complex and is often replaced by a simplified test spectrum, of comparable severity, in the cycling test.

4.4.4.3 Acceptance tests

ECSS-E-ST-32-02_0260182

a. All hardware shall be submitted to the following sequence of tests, or alternative sequence agreed between customer and supplier:

1. initial NDT, in order to establish the initial condition of the hardware;
2. proof pressure test;
3. leak test;
4. final NDT.

NOTE For example:

- The NDT prior to proof test can be substituted for that of the manufacturing process.
- Proof test monitoring by acoustic emission is acceptable for composite items instead of post testing NDT, with customer approval. Detailed acoustic emission procedures, with proven health monitoring capability, are agreed per NDT plan, in line with the general requirements of clauses 5 and 9 of the ECSS-Q-ST-70-15

ECSS-E-ST-32-02_0260183

b. For COPS, initial NDT operations shall be applied to the over-wrap, in addition to NDT on the liner.

ECSS-E-ST-32-02_0260184

c. For CPS, NDT operations shall be applied to the composite wall as a minimum.

ECSS-E-ST-32-02_0260185

d. Clause 5.5 shall be applied to the acceptance tests.

ECSS-E-ST-32-02_0260186

e. Final NDT shall be performed on the over-wrap of the COPS as a minimum.

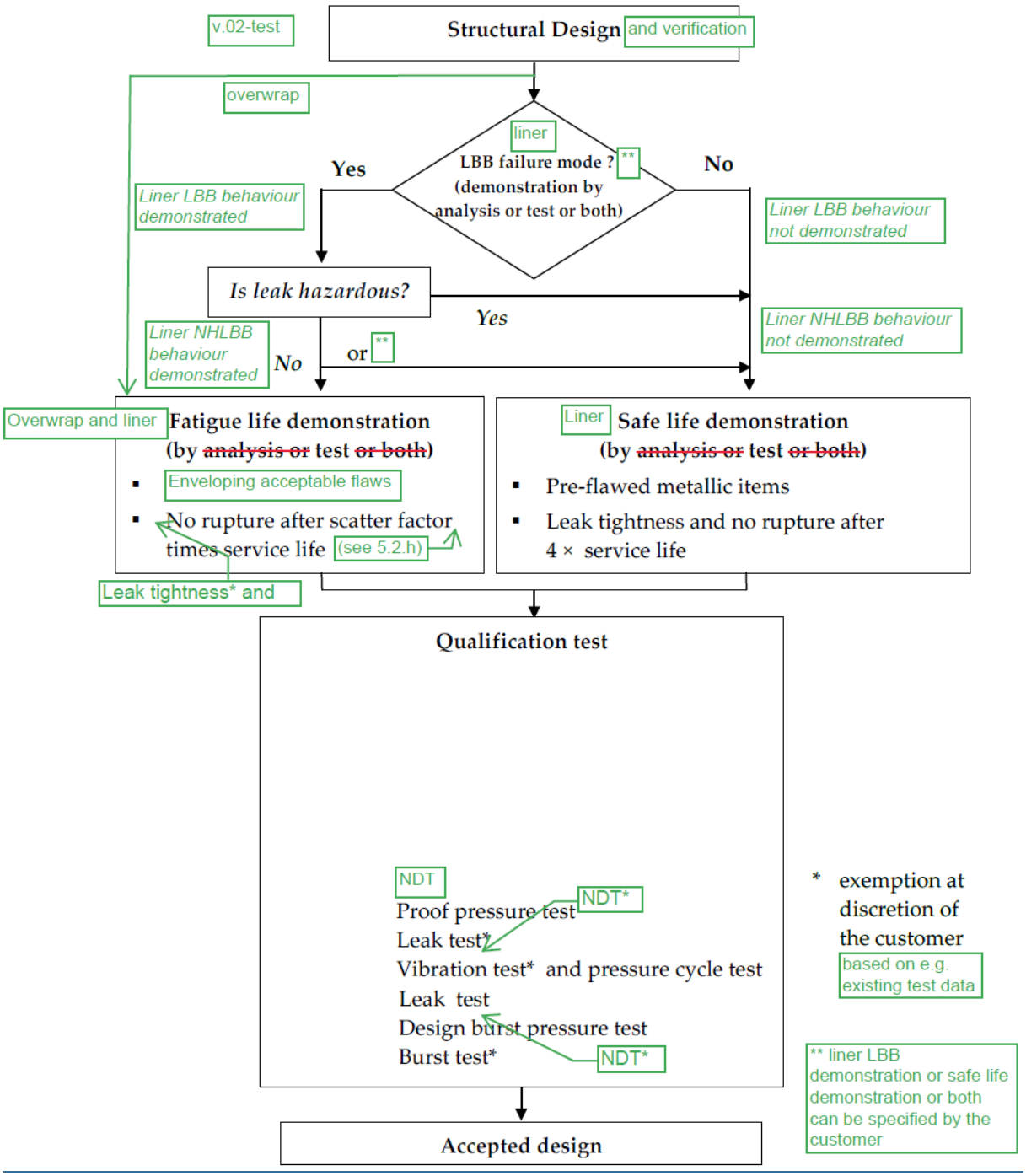

Figure 4-8: Development approach of COPS with homogeneous non metallic liner and CPS

4.5 Pressure components

4.5.1 Metallic pressure components

4.5.1.1 Factors of safety

ECSS-E-ST-32-02_0260187

a. The values in Table 4-1 and Table 4-2 shall be applied as minimum values of factors of safety for internal pressure of metallic pressure components (MPC).

ECSS-E-ST-32-02_0260188

b. The values specified in ECSS-E-ST-32-10 for 'pressurized hardware' shall be applied as minimum values of factors of safety for loads different from internal pressure.

NOTE to items a and b. Exceptions to the values provided in Table 4-1, Table 4-2 or ECSS-E-ST-32-10 are sometimes specified by the customer or granted with customer approval.
Examples of reasons for exceptions: ground/range safety rules, mitigation of concerns due to time dependent phenomena like creep, human safety during the mission.

ECSS-E-ST-32-02_0260431

4.5.1.2 Development approach

ECSS-E-ST-32-02_0260189

a. Clause 5.2 on structural engineering shall be applied.

NOTE Thermal, stress and strain analyses and stiffness, strength and stability demonstrations are sometimes substituted with certification from qualified aerospace suppliers, with customer approval.

ECSS-E-ST-32-02_0260190

b. Qualification tests shall be conducted according to clause 4.5.1.3 to demonstrate the structural adequacy of the design.

ECSS-E-ST-32-02_0260191

c. A 'safe life item' or 'nonhazardous LBB failure mode' demonstration shall be performed by analysis or test or both in conformance with clause 5.3 and ECSS-E-ST-32-01 for metallic pressure components.

NOTE 1 Relevant requirements can be found, for example, in clauses 8.2.1 (Pressurized hardware General), 8.2.4 (Pressure components, including lines and fittings) and 8.2.7 (Pressurized components with non-hazardous LBB failure mode) of the ECSS-E-ST-32-01. Including in particular 8.2.4.b (proof factor 1,5), 8.2.4.c (inspection of fusion joints) and 8.2.1.b (pressure dominance).

NOTE 2 If the criteria of clause 8.2.4.b, 8.2.1.b or 8.2.7 are not met, and the fatigue verification in accordance with item d below is considered insufficient, a crack-growth verification based on initial crack size based on applied NDT can apply.

E CSS-E-ST-32-02_0260192

d. Fatigue-life demonstration shall be performed by analysis or test or both in conformance with clause 5.2.h and ECSS-E-ST-32, considering credible manufacturing imperfections and defects to the extent agreed between customer and supplier.

NOTE 1 No explicit requirement for safe life analysis is specified in 4.5.1.2c and 4.5.1.2d, for items proof pressure tested to a factor 1,5 or higher. For applications, with more critical characteristics, some degree of damage tolerance verification is sometimes performed to mitigate the risk of catastrophic failure in service, as well as providing justification for the applied inspection methods and associated acceptance criteria. These characteristics include, for example:

- subjected to significant non-pressure loads,
- subjected to significant fatigue load cycles,
- human spaceflight applications,
- involving materials and processes with increased risk of creating defects, for example welding, but also brazing, casting, additive manufacturing, (custom) forging processes.

Proof and leak testing alone does not always provide sufficient flaw screening.

NOTE 2 5.2.h specifies a scatter factor of 5 for fatigue analysis.

ECSS-E-ST-32-02_0260193

e. For corrosion control and prevention, the requirements in ECSS-E-ST-32 shall apply.

NOTE ECSS-E-ST-32 refers to ECSS-Q-ST-70 and related standards.

ECSS-E-ST-32-02_0260194

f. For hydrogen embrittlement phenomena, requirements shall be applied in conformance with ECSS-E-ST-32-08.

ECSS-E-ST-32-02_0260195

g. For material selection, material design allowables and their characterisation, requirements shall be applied in conformance with ECSS-E-ST-32.

ECSS-E-ST-32-02_0260196

h. For 'process control', requirements shall be in conformance with ECSS-Q-ST-70.

ECSS-E-ST-32-02_0260197

i. Inspections shall be applied according to clause 5.7.

NOTE For example:

- The development approach is illustrated in Figure 4-9.
- Failure mode demonstration as per clause 5.3 is sometimes specified by the customer.

4.5.1.3 Qualification tests

ECSS-E-ST-32-02_0260198

a. Pressure components other than lines and fittings shall be submitted to the following sequence of tests, or alternative sequence agreed between customer and supplier:

1. NDT;
2. proof pressure test;
3. leak test;
4. NDT;
5. vibration tests;
6. pressure cycling test;
7. leak test;
8. design burst pressure test;
9. burst test.

NOTE This the standard sequence of tests defined in ECSS-E-ST-10-03. Examples of rationale for changes to this sequence are:

- Additional qualification test types (e.g. thermal) or inspection steps (e.g. before burst pressure testing);
- Identified risk that for the particular design the defined sequence can be either unconservative or unnecessarily conservative;
- Omission of test types based on successful heritage or testing of engineering model. Examples: pressure cycling test, burst test, NDT steps.

b. The pressure cycling test specified in 4.5.1.3.a, and the final burst test specified in 4.5.1.3.a may be deleted with customer approval.

NOTE Pressure cycling testing is often waived based on analytical fatigue verification indicating low fatigue damage caused by pressure cycles up to proof pressure level.

ECSS-E-ST-32-02_0260199

c. Lines and fittings, which are joined to an assembly, may be applied without qualification testing, if the geometry is simple and material properties are well characterised.

NOTE Analytical assessment, using conservative or correlated structural models, based on certified material properties, and verified processes like welding and bending can allow to omit formal qualification testing at tube and fitting level.

ECSS-E-ST-32-02_0260200

d. For pressure componentsclause 5.4.1 shall be applied to the qualification tests.

4.5.1.4 Acceptance tests

ECSS-E-ST-32-02_0260201

a. Pressure components shall be submitted to a proof pressure test and a leak test according to clause 5.5.

ECSS-E-ST-32-02_0260202

b. All items with fusion joints shall be submitted to a proof pressure test according to clause 5.5.2.

ECSS-E-ST-32-02_0260203

c. << deleted and moved to Note of 4.5.1.4d>>

ECSS-E-ST-32-02_0260204

d. All fusion joints shall be 100 % inspected by means of a NDT method, defined with customer approval, prior and after the proof pressure test.

NOTE 1 Proof and leak tests can be performed at the assembled pressurized system level.

NOTE 2 For cases where this complete inspection of fusion joints cannot be implemented, relevant additional guidance can be found in ECSS-E-ST-32-01C rev.2, subclause 11.2.2.8, applicable primarily as part of the 'reduced fracture control programme'.

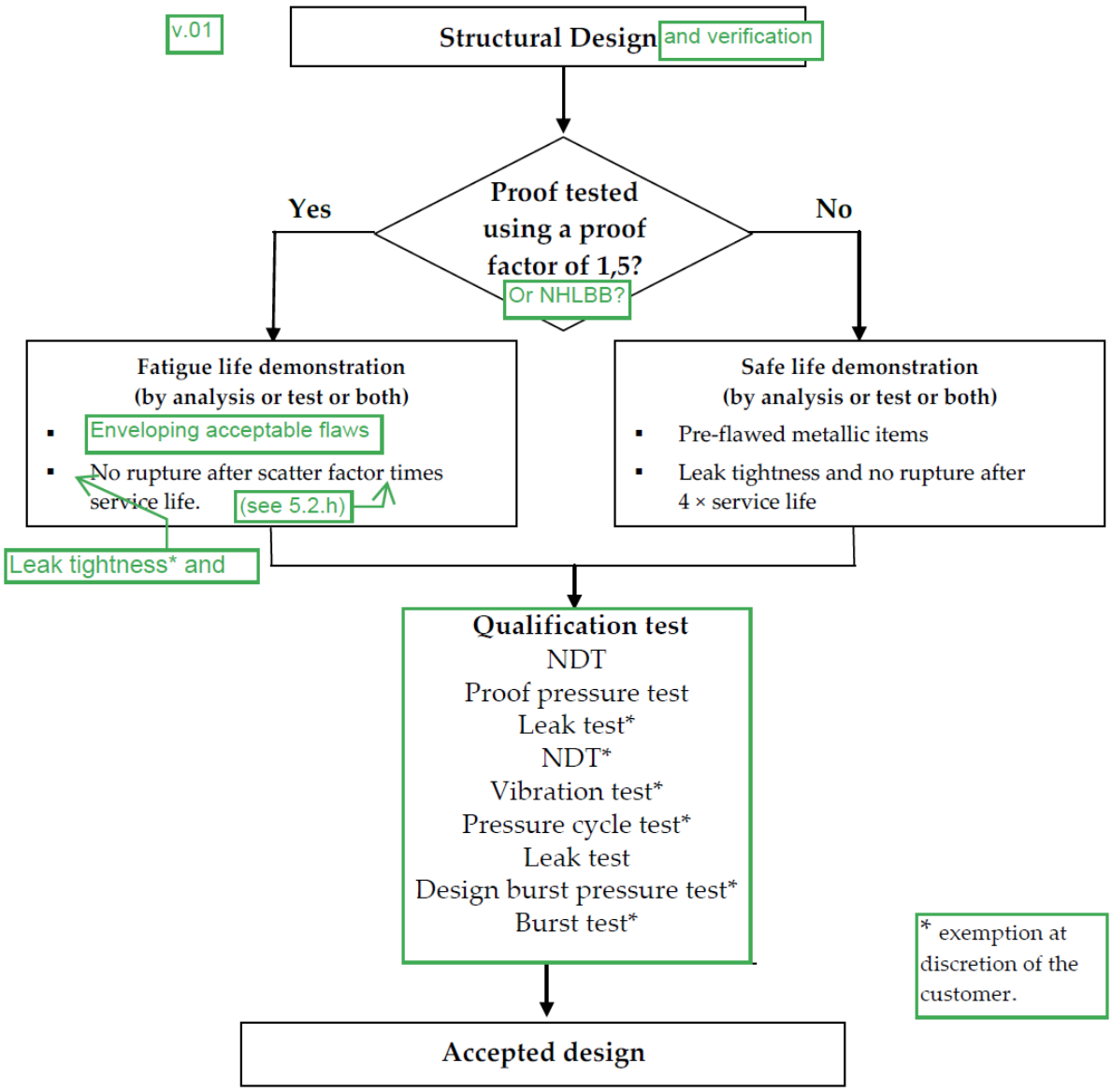

Figure 4-9: Development approach of MPC
(Relevant also for MSPE heat pipes, loop heat pipes, capillary pumped loops)

4.5.2 COPC with metallic liner

4.5.2.1 Factors of safety

ECSS-E-ST-32-02_0260205

a. The values in Table 4-1 and Table 4-2 shall be applied as minimum values of factors of safety for internal pressure of composite overwrapped pressurized components (COPC).

NOTE Exceptions to the values provided in Table 4-1, Table 4-2 or ECSS-E-ST-32-10 are sometimes

specified by the customer or granted with customer approval.

Examples of reasons for exceptions: ground/range safety rules, mitigation of concerns due to time dependent phenomena like creep and for composites stress rupture, human safety during the mission.

When this is the case for a burst factor, the following relations can be used for determination of the proof factor:

$j_{proof} = (1 + j_{burst}) / 2$ when $j_{burst} < 2,0$

$j_{proof} = 1,5$ when $j_{burst} > 2,0$

The FoS specified for COPC are defined the same as pressure vessels, because no established alternate approach exists yet. Development of a tailored approach (in agreement with the customer/safety authority) is expected, based on FoS similar to the ones of metallic pressure components (proof 1,5, burst 2,5 or more), but addressing additional concerns associated with for example barely visible impact damage and thermo-mechanical loads. Fulfilling the pressure vessel requirements can be impractical.

ECSS-E-ST-32-02_0260206

b. The values specified in ECSS-E-ST-32-10 for 'pressurized hardware' shall be applied as minimum values of factors of safety for loads different from internal pressure.

NOTE Exceptions to the values provided in Table 4-1, Table 4-2 or ECSS-E-ST-32-10 are sometimes specified by the customer or granted with customer approval.

Examples of reasons for exceptions: ground/range safety rules, mitigation of concerns due to time dependent phenomena like creep and for composites stress rupture, human safety during the mission.

When this is the case for a burst factor, the following relations can be used for determination of the proof factor:

$j_{proof} = (1 + j_{burst}) / 2$ when $j_{burst} < 2,0$

$j_{proof} = 1,5$ when $j_{burst} \geq 2,0$

The FoS specified for COPC are defined the same as pressure vessels, because no established alternate approach exists yet. Development of a tailored approach (in agreement with the customer/safety

authority) is expected, based on FoS similar to the ones of metallic pressure components (proof 1,5, burst 2,5 or more), but addressing additional concerns associated with for example barely visible impact damage and thermo-mechanical loads. Fulfilling the pressure vessel requirements can be impractical.

ECSS-E-ST-32-02_0260432

4.5.2.2 Development approach

ECSS-E-ST-32-02_0260207

a. Clause 5.2 on structural engineering shall be applied.

ECSS-E-ST-32-02_0260208

b. A stiffness demonstration shall be performed by analysis and test.

ECSS-E-ST-32-02_0260209

c. A strength and stability demonstration shall be performed by analysis and test.

ECSS-E-ST-32-02_0260210

d. If specified, or relevant to comply with 4.5.2.2.d, the LBB failure mode shall be demonstrated by analysis or test or both according to clause 5.3.

ECSS-E-ST-32-02_0260211

e. For metallic COPC liners with a non-hazardous LBB failure mode, the safe-life demonstration specified in 4.5.2.2.1f may be replaced by a fatigue life demonstration by analysis or test or both in conformance with clause 5.2.h and ECSS-E-ST-32, considering credible manufacturing imperfections and defects to the extent agreed between customer and supplier.

NOTE This can have an impact on the mission reliability. If a project is rated highly critical by the customer due to considerations other than safety, safe life to leakage verification of the metallic liner is sometimes requested instead of, or in addition to, LBB verification .
It is recommended that this agreement is achieved as early as possible, for example in the statement of work and associated baseline requirements, and then reflected in the Fracture Control Plan.

ECSS-E-ST-32-02_0260212

f. Except in the case specified in 4.5.2.2.e, 'safe life item' demonstration shall be performed for the metallic liner by analysis or test or both in conformance with ECSS-E-ST-32-01.

ECSS-E-ST-32-02_0260213

g. Fatigue-life demonstration shall be performed for the composite over-wrap by analysis or test or both in conformance with ECSS-E-ST-32.

ECSS-E-ST-32-02_0260214

h. Qualification tests shall be conducted according to clause 4.5.2.3 to demonstrate the structural adequacy of the design.

ECSS-E-ST-32-02_0260215

i. For corrosion control and prevention, the requirements in ECSS-E-ST-32 shall apply.

NOTE ECSS-E-ST-32 refers to ECSS-Q-ST-70 and related standards.

ECSS-E-ST-32-02_0260216

j. For hydrogen embrittlement phenomena, requirements shall be applied in conformance with ECSS-E-ST-32-08.

ECSS-E-ST-32-02_0260217

k. For material selection, material design allowables and their characterisation, requirements shall be applied in conformance with clause 5.6 and ECSS-E-ST-32.

ECSS-E-ST-32-02_0260218

l. For 'process control', requirements shall be in conformance with ECSS-Q-ST-70.

ECSS-E-ST-32-02_0260219

m. Inspections shall be applied according to clause 5.7.

NOTE The development approach is illustrated in Figure 4-4.

4.5.2.3 Qualification tests

ECSS-E-ST-32-02_0260220

a. A first qualification test article shall be submitted to the following sequence of tests, or alternative sequence agreed between customer and supplier:

1. non-destructive testing (NDT);
2. proof pressure test;
3. leak test;
4. NDT;
5. pressure cycling test;
6. leak test;
7. design burst pressure test;
8. burst test.

NOTE This the standard sequence of tests defined in ECSS-E-ST-10-03. Examples of rationale for changes to this sequence are:

- Additional qualification test types (e.g. thermal) or inspection steps (e.g. before burst pressure testing);
- Identified risk that for the particular design the defined sequence can be either unconservative or unnecessarily conservative
- Omission of test types based on successful heritage or testing of engineering model. Examples: pressure cycling test, burst test, NDT steps.

ECSS-E-ST-32-02_0260454

b. The first qualification test article specified in 4.5.2.3a may be deleted with customer approval.

NOTE Examples of rationale for deletion of a formal first qualification test article:

- Similarity with a qualified vessel giving confidence in the robustness of the design and manufacturing processes;
- Successful testing of a representative engineering model.
- Additional factors that can be considered: simplicity of the design, actual margins, heritage of the supplier.

ECSS-E-ST-32-02_0260222

c. A second qualification test article shall be submitted to the following sequence of tests, or alternative sequence agreed between customer and supplier:

1. NDT;
2. proof pressure test;

3. leak test;
4. NDT;
5. vibration tests;
6. pressure cycling test;
7. leak test;
8. design burst pressure test;
9. burst test.

NOTE This the standard sequence of tests defined in ECSS-E-ST-10-03. Examples of rationale for changes to this sequence are:

- Additional qualification test types (e.g. thermal) or inspection steps;
- Identified risk that for the particular design the defined sequence can be either unconservative or unnecessarily conservative.
- Omission of test types based on successful heritage or testing of engineering model.

ECSS-E-ST-32-02_0260455

d. The leak test and NDT after proof pressure test specified in 4.5.2.3c, and the final burst test specified in 4.5.2.3c may be deleted with customer approval.

ECSS-E-ST-32-02_0260456

e. When the vibration loads are enveloped by the other qualification tests, the vibration tests specified in 4.5.2.3c may be deleted with customer approval.

ECSS-E-ST-32-02_0260225

f. NDT operations shall be applied to the over-wrap, in addition to NDT on the liner.

ECSS-E-ST-32-02_0260226

g. Clause 5.4 shall be applied to the qualification tests.

ECSS-E-ST-32-02_0260227

h. The need to apply external loads in combination with internal pressure during qualification testing shall be considered taking into account their relative magnitude, the fatigue and destabilizing effects of external loads.

NOTE This is considered, for example, for cases where locally or globally non-pressure loads are significant, and applicable yield or ultimate

combined load cases are not covered by proof or burst testing, contradicting to some extent the characteristic that pressure loads are dominant, and where it is not acceptable to cover the difference by analysis, similarity, test on design detail, etc. In vibration testing the vibration loads, per axis, will actually apply the strength qualification factor of 1,25, but no factor, like FOSY or FOSU, on pressure.

ECSS-E-ST-32-02_0260228

i. If external cycling loads are applied, the load shall be cycled to limit for four times the predicted number of operating cycles of the most severe design condition.

NOTE Examples: Destabilizing load with constant minimum internal pressure or maximum additive load with a constant MDP.
The actual cycle life can be complex and is often replaced by a simplified test spectrum, of comparable severity, in the cycling test.

4.5.2.4 Acceptance tests

ECSS-E-ST-32-02_0260229

a. All hardware shall be submitted to the following sequence of tests, or alternative sequence agreed between customer and supplier:

1. initial NDT, in order to establish the initial condition of the hardware;
2. proof pressure test;
3. leak test;
4. final NDT.

NOTE For example:

- The NDT prior to proof test can be substituted for that of the manufacturing process.
- Proof test monitoring by acoustic emission is acceptable for composite items instead of post testing NDT, with customer approval. Detailed acoustic emission procedures, with proven health monitoring capability, are agreed per NDT plan, in line with the general requirements of clauses 5 and 9 of the ECSS-Q-ST-70-15.

ECSS-E-ST-32-02_0260230

b. Initial NDT operations shall be applied to the over-wrap, in addition to NDT on the liner.

ECSS-E-ST-32-02_0260231

c. Clause 5.5 shall be applied to the acceptance tests.

ECSS-E-ST-32-02_0260232

d. Final NDT shall be performed on the over-wrap of the COPC as a minimum.

4.5.3 COPC with homogeneous non metallic liner

4.5.3.1 Factors of safety

ECSS-E-ST-32-02_0260233

a. The values in Table 4-1 and Table 4-2 shall be applied as minimum values of factors of safety for internal pressure of composite overwrapped pressurized components (COPC).

NOTE Exceptions to the values provided in are sometimes specified by the customer or granted with customer approval.

Examples of reasons for exceptions: ground/range safety rules, mitigation of concerns due to time dependent phenomena like creep and for composites stress rupture, human safety during the mission.

When this is the case for a burst factor, the following relations can be used for determination of the proof factor:

$j_{proof} = (1 + j_{burst}) / 2$ when $j_{burst} < 2{,}0$

$j_{proof} = 1{,}5$ when $j_{burst} > 2{,}0$

ECSS-E-ST-32-02_0260234

b. The values specified in ECSS-E-ST-32-10 for 'pressurized hardware' shall be applied as minimum values of factors of safety for loads different from internal pressure.

NOTE Exceptions to the values provided in are sometimes specified by the customer or granted with customer approval.

Examples of reasons for exceptions: ground/range safety rules, mitigation of concerns due to time dependent phenomena like creep and for composites stress rupture, human safety during the mission.

When this is the case for a burst factor, the following relations can be used for determination of the proof factor:

$j_{proof} = (1 + j_{burst}) / 2$ when $j_{burst} < 2,0$

$j_{proof} = 1,5$ when $j_{burst} \geq 2,0$

ECSS-E-ST-32-02_0260433

4.5.3.2 Development approach

ECSS-E-ST-32-02_0260235

a. Clause 5.2 on structural engineering shall be applied.

ECSS-E-ST-32-02_0260236

b. A stiffness demonstration shall be performed by analysis and test.

ECSS-E-ST-32-02_0260237

c. A strength and stability demonstration shall be performed by analysis and test.

ECSS-E-ST-32-02_0260238

d. The LBB failure mode shall be demonstrated by test using a method agreed with the customer.

NOTE Experience with non-metallic lined COPC is limited, and LBB failure mode demonstration according to 5.3 can be difficult or not relevant (see also e and f below). No definite requirements are therefore provided in this standard on whether and how to apply clause 5.3, and specifically 5.3.4 (Demonstration of LBB by test using full-scale article).

ECSS-E-ST-32-02_0260239

e. The liner of the COPC shall exhibit a LBB failure mode.

NOTE The fulfilment of this requirement is sometimes possible without LBB analysis or test per 5.3, for liners that do not experience significant load when compared to the overwrap. Example: thermoplastic liner, see e.g. AIAA G-082.

ECSS-E-ST-32-02_0260457

f. When the non-metallic liner of the COPC remains in compression up to MDP and surface flaws do not propagate during the LBB test, the flaws pre-fabricated in the liner of the LBB full-scale specimen may be through cracks.

ECSS-E-ST-32-02_0260241

g. 'Safe life item' demonstration of the liner shall be performed in conformance with ECSS-E-ST-32-01:

by test for non-metallic items;

by analysis or test or both for metallic items (e.g. metallic bosses).

ECSS-E-ST-32-02_0260242

h. Qualification tests shall be conducted according to clause 4.5.3.3 to demonstrate the structural adequacy of the design.

ECSS-E-ST-32-02_0260243

i. For corrosion control and prevention, the requirements in ECSS-E-ST-32 shall apply.

NOTE ECSS-E-ST-32 refers to ECSS-Q-ST-70 and related standards.

ECSS-E-ST-32-02_0260244

j. For hydrogen embrittlement phenomena, requirements shall be applied in conformance with ECSS-E-ST-32-08.

ECSS-E-ST-32-02_0260245

k. For material selection, material design allowables and their characterisation, requirements shall be applied in conformance with clause 5.6 and ECSS-E-ST-32.

ECSS-E-ST-32-02_0260246

l. For 'process control', requirements shall be in conformance with ECSS-Q-ST-70.

ECSS-E-ST-32-02_0260247

m. Inspections shall be applied according to clause 5.7.

NOTE The development approach is illustrated in Figure 4-5.

n. Fatigue-life demonstration shall be performed for the composite over-wrap by analysis or test or both in conformance with ECSS-E-ST-32.

NOTE The development approach is illustrated in Figure 4-5.

4.5.3.3 Qualification tests

ECSS-E-ST-32-02_0260248

a. A first qualification test article shall be submitted to the following sequence of tests, or alternative sequence agreed between customer and supplier:

1. non-destructive testing (NDT);
2. proof pressure test;
3. leak test;
4. NDT;
5. pressure cycling test;
6. leak test;
7. design burst pressure test;
8. burst test.

NOTE This the standard sequence of tests defined in ECSS-E-ST-10-03. Examples of rationale for changes to this sequence are:

- Additional qualification test types (e.g. thermal) or inspection steps (e.g. before burst pressure testing);
- Identified risk that for the particular design the defined sequence can be either unconservative or unnecessarily conservative.
- Omission of test types based on successful heritage or testing of engineering model. Examples: pressure cycling test, burst test, NDT steps.

ECSS-E-ST-32-02_0260458

b. The first qualification test article specified in 4.5.3.3a may be deleted with customer approval.

NOTE Examples of rationale for deletion of a formal first qualification test article:

- Similarity with a qualified vessel giving confidence in the robustness of the design and manufacturing processes;
- Successful testing of a representative engineering model.
- Additional factors that can be considered: simplicity of the design, actual margins, heritage of the supplier.

ECSS-E-ST-32-02_0260250

c. A second qualification test article shall be submitted to the following sequence of tests, or alternative sequence agreed between customer and supplier:

1. NDT;
2. proof pressure test;
3. leak test;
4. NDT;
5. vibration tests;
6. pressure cycling test;
7. leak test;
8. design burst pressure test;
9. burst test.

NOTE This the standard sequence of tests defined in ECSS-E-ST-10-03. Examples of rationale for changes to this sequence are:

- Additional qualification test types (e.g. thermal) or inspection steps;
- Identified risk that for the particular design the defined sequence can be either unconservative or unnecessarily conservative.
- Omission of test types based on successful heritage or testing of engineering model.

ECSS-E-ST-32-02_0260459

d. The leak test and NDT after proof pressure test specified in 4.5.3.3c, and the final burst test specified in 4.5.3.3c may be deleted with customer approval.

ECSS-E-ST-32-02_0260460

e. When the vibration loads are enveloped by the other qualification tests, the vibration tests specified in 4.5.3.3c may be deleted with customer approval.

ECSS-E-ST-32-02_0260253

f. NDT operations shall be applied to the over-wrap, in addition to NDT on the liner.

ECSS-E-ST-32-02_0260254

g. Clause 5.4 shall be applied to the qualification tests.

ECSS-E-ST-32-02_0260255

h. The need to apply external loads in combination with internal pressure during qualification testing shall be considered taking into account their relative magnitude, the fatigue and destabilizing effects of external loads.

NOTE This is considered, for example, for cases where locally or globally non-pressure loads are significant, and applicable yield or ultimate combined load cases are not covered by proof or burst testing, contradicting to some extent the characteristic that pressure loads are dominant, and where it is not acceptable to cover the difference by analysis, similarity, test on design detail, etc. In vibration testing the vibration loads, per axis, will actually apply the strength qualification factor of 1,25, but no factor, like FOSY or FOSU, on pressure.

ECSS-E-ST-32-02_0260256

i. If external cycling loads are applied, the load shall be cycled to limit for four times the predicted number of operating cycles of the most severe design condition.

NOTE Examples: Destabilizing load with constant minimum internal pressure or maximum additive load with a constant MDP.
The actual cycle life can be complex and is often replaced by a simplified test spectrum, of comparable severity, in the cycling test.

4.5.3.4 Acceptance tests

ECSS-E-ST-32-02_0260257

a. All hardware shall be submitted to the following sequence of tests, or alternative sequence agreed between customer and supplier:

1. initial NDT, in order to establish the initial condition of the hardware;
2. proof pressure test;
3. leak test;
4. final NDT.

NOTE For example:

- The NDT prior to proof test can be substituted for that of the manufacturing process.
- Proof test monitoring by acoustic emission is acceptable for composite items instead of post testing NDT, with customer approval. Detailed acoustic emission procedures, with proven

health monitoring capability, are agreed per NDT plan, in line with the general requirements of clauses 5 and 9 of the ECSS-Q-ST-70-15.

ECSS-E-ST-32-02_0260258

b. Initial NDT operations shall be applied to the over-wrap, in addition to NDT on the liner.

ECSS-E-ST-32-02_0260259

c. Clause 5.5 shall be applied to the acceptance tests.

ECSS-E-ST-32-02_0260260

d. Final NDT shall be performed on the over-wrap of the COPC as a minimum.

4.6 Special pressurized equipment

4.6.1 Metallic special pressurized equipment

4.6.1.1 Factors of safety

ECSS-E-ST-32-02_0260261

a. The values in Table 4-1 and Table 4-2 shall be applied as minimum values of factors of safety for internal pressure of the different categories of metallic special pressurized equipment (MSPE).

NOTE Exceptions to the values provided in Table 4-1, Table 4-2 or ECSS-E-ST-32-10 are sometimes specified by the customer or granted with customer approval.
Examples of reasons for exceptions: ground/range safety rules, mitigation of concerns due to time dependent phenomena like creep, human safety during the mission, selected fracture control approach.

ECSS-E-ST-32-02_0260262

b. The values specified in ECSS-E-ST-32-10 for 'pressurized hardware' shall be applied as minimum values of factors of safety for loads different from internal pressure.

NOTE Exceptions to the values provided in Table 4-1, Table 4-2 or ECSS-E-ST-32-10 are sometimes specified by the customer or granted with customer approval.

Examples of reasons for exceptions: ground/range safety rules, mitigation of concerns due to time dependent phenomena like creep, human safety during the mission, selected fracture control approach.

ECSS-E-ST-32-02_0260434

4.6.1.2 Development approach

ECSS-E-ST-32-02_0260263

a. Clause 5.2 on structural engineering shall be applied.

NOTE Thermal, stress and strain analyses and stiffness, strength and stability demonstrations are sometimes substituted with certification from qualified aerospace suppliers, with customer approval.

ECSS-E-ST-32-02_0260264

b. <<deleted>>

ECSS-E-ST-32-02_0260265

c. <<deleted>>

ECSS-E-ST-32-02_0260266

d. <<deleted>>.

ECSS-E-ST-32-02_0260267

e. Qualification tests shall be conducted according to 4.6.1.3 to demonstrate the structural adequacy of the design.

ECSS-E-ST-32-02_0260268

f. A ‘safe life item’ or ‘nonhazardous LBB failure mode’ demonstration shall be performed by analysis or test or both in conformance with clause 5.3 and ECSS-E-ST-32-01 for metallic special pressurized equipment.

NOTE 1 For metallic sealed containers, cryostats and batteries (non-hazardous leakage) relevant subclauses of ECSS-E-ST-32-01 include 6.3.2 (Safe life items) or 8.2.5 (Low risk sealed containers) and 8.2.1 (Pressurized hardware - General). Sealed containers, and hence also cryostats and batteries, with MDP >0,3 MPa or which cannot be demonstrated as NHLBB according to 5.3 (i.e. do not meet clause 8.2.5 of ECSS-E-ST-32-01C), are verified as safe life items.

NOTE 2 For metallic heat pipes, loop heat pipes, capillary pumped loops relevant subclauses of ECSS-E-ST-32-01C include 8.2.4 (Pressure components), 8.2.7 (Pressurized components with nonhazardous LBB failure mode) and 8.2.1 (Pressurized hardware - General). Including in particular 8.2.4.b (proof factor 1,5), 8.2.4.c (inspection of fusion joints) and 8.2.1.b (pressure dominance).

NOTE 3 For metallic hazardous fluid containers, cryostats and batteries (hazardous leakage) relevant subclauses of ECSS-E-ST-32-01C include 8.2.6 (Hazardous fluid containers) and 8.2.1 (Pressurized hardware - General). Including in particular 8.2.1.b (pressure dominance). Clause 8.2.6 of ECSS-E-ST-32-01C considers hazardous fluid containers with MDP >0,15 MPa as pressure vessels. 'Nonhazardous LBB failure mode' demonstration does not apply to hazardous fluid containers due to the hazardous content.

NOTE 4 If the criteria of clause 8.2.4.b, 8.2.1.b or 8.2.7 are not met, and the fatigue verification in accordance with item g below is considered insufficient, a crack-growth verification based on initial crack size based on applied NDT can apply.

ECSS-E-ST-32-02_0260269

g. Fatigue-life demonstration shall be performed by analysis or test or both in conformance with ECSS-E-ST-32, considering credible manufacturing imperfections and defects to the extent agreed between customer and supplier.

NOTE No explicit requirement for safe life analysis is defined in 4.6.1.2f and 4.6.1.2g, for items proof pressure tested to a factor 1,5 or higher. For applications, with more critical characteristics, some degree of damage tolerance verification is sometimes performed to mitigate the risk of catastrophic failure in service, as well as providing justification for the applied inspection methods and associated acceptance criteria. These characteristics include, for example:

- subjected to significant non-pressure loads,
- subjected to significant fatigue load cycles,
- human spaceflight applications,
- involving materials and processes with increased risk of creating defects, for example welding, but also brazing, casting, additive manufacturing, (custom) forging processes.

Proof and leak testing alone does not always provide sufficient flaw screening.

ECSS-E-ST-32-02_0260270

h. For corrosion control and prevention, the requirements in ECSS-E-ST-32 shall apply.

NOTE ECSS-E-ST-32 refers to ECSS-Q-ST-70 and related standards.

ECSS-E-ST-32-02_0260271

i. For hydrogen embrittlement phenomena, requirements shall be applied in conformance with ECSS-E-ST-32-08.

ECSS-E-ST-32-02_0260272

j. For material selection, material design allowables and their characterisation, requirements shall be applied in conformance with ECSS-E-ST-32.

ECSS-E-ST-32-02_0260273

k. For 'process control', requirements shall be in conformance with ECSS-Q-ST-70.

ECSS-E-ST-32-02_0260274

l. Inspections shall be applied according to clause 5.7.

NOTE 1 The development approach for metallic sealed containers is illustrated in Figure 4-10.

NOTE 2 The development approach for metallic cryostats (or Dewars) and batteries is illustrated in Figure 4-10 (non-hazardous leakage) and Figure 4-13 (hazardous leakage).

NOTE 3 The development approach for metallic heat pipes, loop heat pipes, capillary pumped loops is illustrated in Figure 4-9.

NOTE 4 The development approach for metallic hazardous fluids containers is illustrated in Figure 4-13.

NOTE 5 Failure mode demonstration as per clause 5.3 is sometimes specified for heat pipes by the customer.

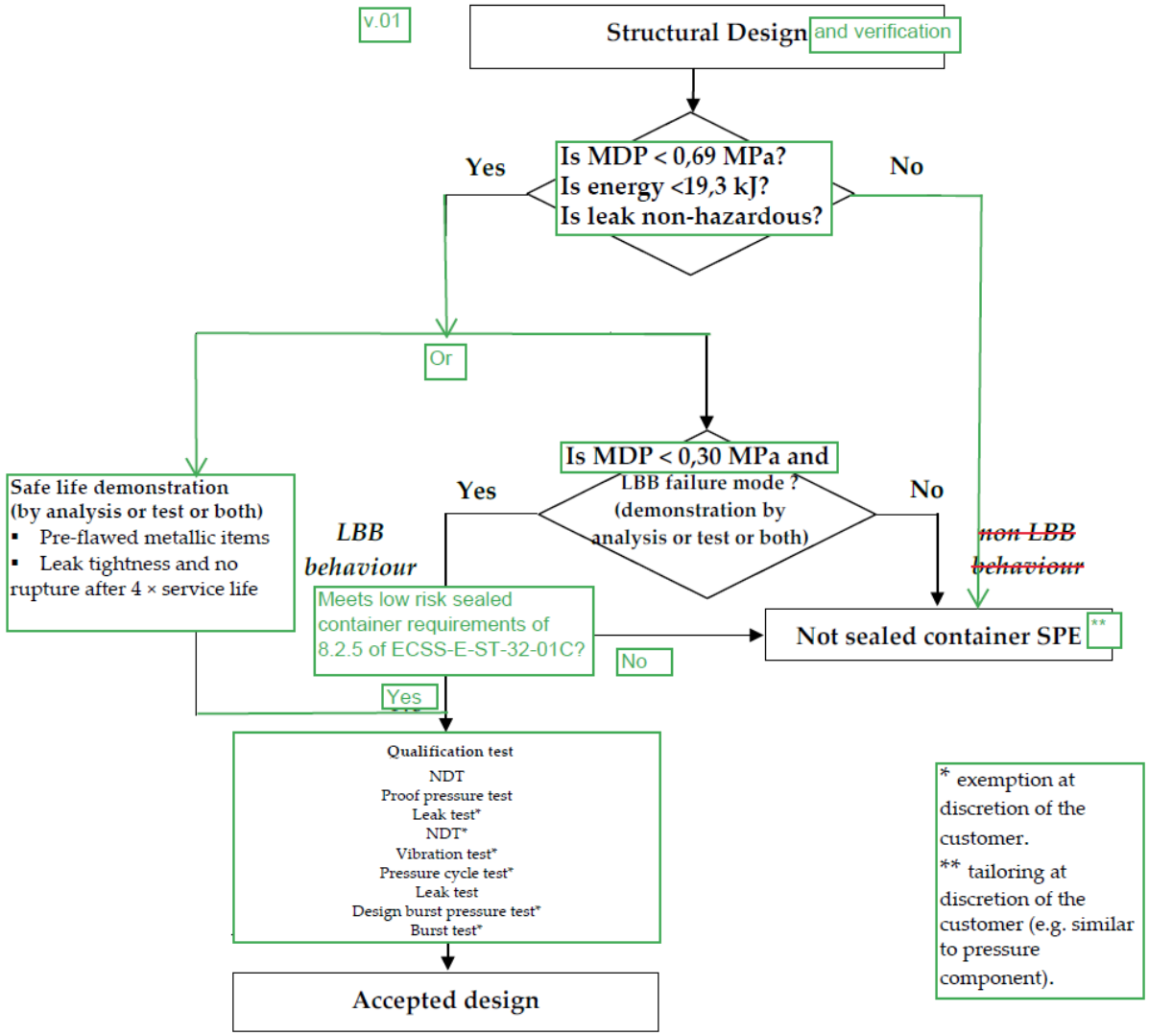

Figure 4-10: Development approach of metallic sealed containers
(Relevant also for MSPE cryostats (Dewars) and batteries (non-hazardous leakage))

Figure 4-11: Deleted

Figure 4-12: Deleted

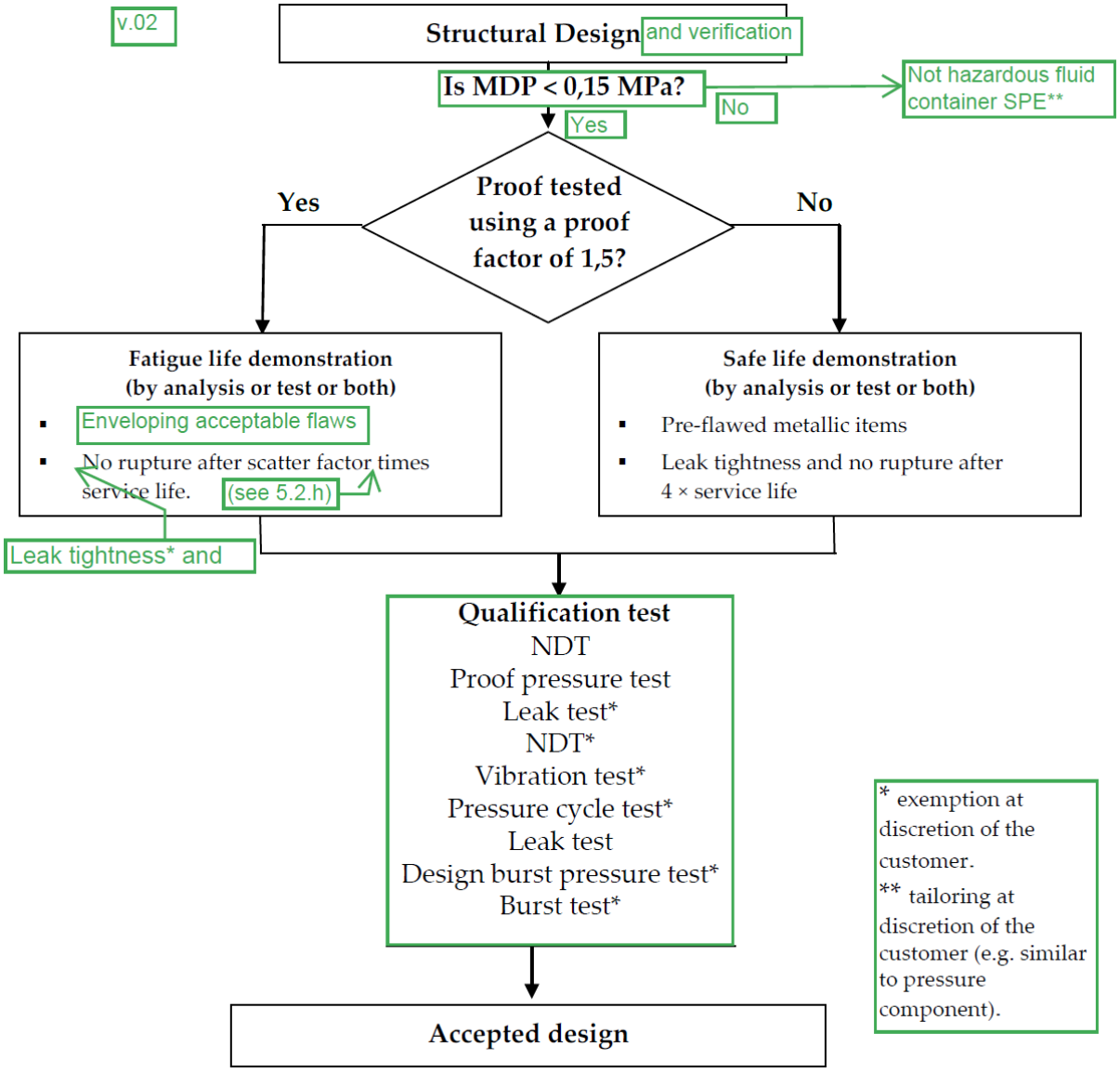

Figure 4-13: Development approach of metallic hazardous fluid containers (Relevant also for MSPE cryostats (Dewars) and batteries (hazardous leakage))

4.6.1.3 Qualification tests

ECSS-E-ST-32-02_0260275

a. All cryostats shall be submitted to the following sequence of tests, or alternative sequence agreed between customer and supplier:

1. NDT;
2. proof pressure test;
3. leak test;
4. NDT;
5. vibration tests;

6. pressure cycling test;
7. leak test;
8. design burst pressure test;
9. burst test.

NOTE This the standard sequence of tests defined in ECSS-E-ST-10-03. Examples of rationale for changes to this sequence are:

- Additional qualification test types (e.g. thermal) or inspection steps (e.g. before burst pressure testing);
- Identified risk that for the particular design the defined sequence can be either unconservative or unnecessarily conservative;
- Omission of test types based on successful heritage or testing of engineering model. Examples: pressure cycling test, burst test, NDT steps.

ECSS-E-ST-32-02_0260276

b. <<deleted, covered by 4.6.1.3a>>

ECSS-E-ST-32-02_0260277

c. <<deleted>>

ECSS-E-ST-32-02_0260278

d. <<deleted>>

ECSS-E-ST-32-02_0260279

e. Clause 5.4 shall be applied to the qualification tests.

4.6.1.4 Acceptance tests

ECSS-E-ST-32-02_0260280

a. Metallic SPE shall be submitted to a proof pressure test, except for those meeting the requirements of clause 8.2.5a or 8.2.5.b.1 of ECSS-E-ST-32-01.

NOTE Requirement 8.2.5.a of ECSS-E-ST-32-01 addresses sealed containers with MDP not exceeding 0,15 MPa, while clause 8.2.5.b.1 addresses sealed containers with MDP between 0,15 MPa and 0,30 MPa.

ECSS-E-ST-32-02_0260281

b. Metallic SPE shall be submitted to a leak test at MDP, unless agreed otherwise with the customer.

NOTE in cases where leak testing is impractical, e.g. after sealing the item, alternative acceptance or process control practices are agreed that provide adequate assurance of absence of detrimental leakage.

ECSS-E-ST-32-02_0260282

c. Fusion joints shall be 100 % inspected by means of a NDT method, defined with customer approval, prior and after the proof pressure test.

NOTE For cases where this cannot be implemented, relevant additional guidance can be found in ECSS-E-ST-32-01C Rev.2 clause 11.2.2.8, applicable primarily as part of the 'reduced fracture control programme'.

ECSS-E-ST-32-02_0260283

d. <<deleted>>

ECSS-E-ST-32-02_0260284

e. <<deleted>>

ECSS-E-ST-32-02_0260285

f. Clauses 5.5.1, 5.5.2, and 5.5.3 shall be applied to the acceptance tests.

NOTE Proof and leak tests can be performed at the assembled pressurized system level.

4.6.2 COSPE with metallic liner

4.6.2.1 Factors of safety

ECSS-E-ST-32-02_0260286

a. The values in Table 4-1 and Table 4-2 shall be applied as minimum values of factors of safety for internal pressure of composite overwrapped special pressurized equipment (COSPE).

NOTE Exceptions to the values provided in Table 4-1, Table 4-2 or ECSS-E-ST-32-10 are sometimes specified by the customer or granted with customer approval.

Examples of reasons for exceptions: ground/range safety rules, mitigation of concerns due to time dependent phenomena like creep and for

composites stress rupture, human safety during the mission.

When this is the case for a burst factor, the following relations can be used for determination of the proof factor:

$j_{proof} = (1 + j_{burst}) / 2$ when $j_{burst} < 2,0$

$j_{proof} = 1,5$ when $j_{burst} > 2,0$

ECSS-E-ST-32-02_0260287

b. The values specified in ECSS-E-ST-32-10 for 'pressurized hardware' shall apply as minimum values of factors of safety for loads different from internal pressure.

NOTE Exceptions to the values provided in Table 4-1, Table 4-2 or ECSS-E-ST-32-10 are sometimes specified by the customer or granted with customer approval.

Examples of reasons for exceptions: ground/range safety rules, mitigation of concerns due to time dependent phenomena like creep and for composites stress rupture, human safety during the mission.

When this is the case for a burst factor, the following relations can be used for determination of the proof factor:

$j_{proof} = (1 + j_{burst}) / 2$ when $j_{burst} < 2,0$

$j_{proof} = 1,5$ when $j_{burst} \geq 2,0$

ECSS-E-ST-32-02_0260435

4.6.2.2 Development approach

ECSS-E-ST-32-02_0260288

a. Clause 5.2 on structural engineering shall be applied.

ECSS-E-ST-32-02_0260289

b. A stiffness demonstration shall be performed by analysis and test.

ECSS-E-ST-32-02_0260290

c. A strength and stability demonstration shall be performed by analysis and test.

ECSS-E-ST-32-02_0260291

d. If specified, or relevant to comply with 4.6.2.2.d, the LBB failure mode shall be demonstrated by analysis or test or both according to clause 5.3.

ECSS-E-ST-32-02_0260292

e. For metallic COSPE liners with a non-hazardous LBB failure mode, the safe-life demonstration specified in 4.6.2.2.1f may be replaced by a fatigue life demonstration by analysis or test or both in conformance with clause 5.2.h and ECSS-E-ST-32, considering credible manufacturing imperfections and defects to the extent agreed between customer and supplier. .

NOTE This can have an impact on the mission reliability. If a project is rated highly critical by the customer due to considerations other than safety, safe life to leakage verification of the metallic liner is sometimes requested instead of, or in addition to, LBB verification .
It is recommended that this agreement is achieved as early as possible, for example in the statement of work and associated baseline requirements, and then reflected in the Fracture Control Plan.

ECSS-E-ST-32-02_0260293

f. Except in the case specified in 4.6.2.2.e, 'safe life item' demonstration shall be performed for the metallic liner by analysis or test or both in conformance with ECSS-E-ST-32-01.

ECSS-E-ST-32-02_0260294

g. Fatigue-life demonstration shall be performed for the composite over-wrap by analysis or test or both in conformance with ECSS-E-ST-32.

ECSS-E-ST-32-02_0260295

h. Qualification tests shall be conducted in conformance with clause 4.6.2.3 to demonstrate the structural adequacy of the design.

ECSS-E-ST-32-02_0260296

i. For corrosion control and prevention, the requirements in ECSS-E-ST-32 shall apply.

NOTE ECSS-E-ST-32 refers to ECSS-Q-ST-70 and related standards.

ECSS-E-ST-32-02_0260297

j. For hydrogen embrittlement phenomena, requirements shall be applied in conformance with ECSS-E-ST-32-08.

ECSS-E-ST-32-02_0260298

k. For material selection, material design allowables and their characterisation, requirements shall be applied in conformance with clause 5.6 and ECSS-E-ST-32.

ECSS-E-ST-32-02_0260299

l. For ‘process control’, requirements shall be in conformance with ECSS-Q-ST-70.

ECSS-E-ST-32-02_0260300

m. Inspections shall be applied according to clause 5.7.

NOTE The development approach is illustrated in Figure 4-4.

4.6.2.3 Qualification tests

ECSS-E-ST-32-02_0260301

a. A first qualification test article shall be submitted to the following sequence of tests, or alternative sequence agreed between customer and supplier:

1. non-destructive testing (NDT);
2. proof pressure test;
3. leak test;
4. NDT;
5. pressure cycling test;
6. leak test;
7. design burst pressure test;
8. burst test.

NOTE This the standard sequence of tests defined in ECSS-E-ST-10-03. Examples of rationale for changes to this sequence are:

- Additional qualification test types (e.g. thermal) or inspection steps (e.g. before burst pressure testing);
- Identified risk that for the particular design the defined sequence can be either unconservative or unnecessarily conservative
- Omission of test types based on successful heritage or testing of engineering model. Examples: pressure cycling test, burst test, NDT steps.

ECSS-E-ST-32-02_0260461

b. The first qualification test article specified in 4.6.2.3a may be deleted with customer approval.

NOTE Examples of rationale for deletion of a formal first qualification test article:

- Similarity with a qualified vessel giving confidence in the robustness of the design and manufacturing processes;
- Successful testing of a representative engineering model.
- Additional factors that can be considered: simplicity of the design, actual margins, heritage of the supplier.

ECSS-E-ST-32-02_0260303

c. A second qualification test article shall be submitted to the following sequence of tests, or alternative sequence agreed between customer and supplier:

1. NDT;
2. proof pressure test;
3. leak test;
4. NDT;
5. vibration tests;
6. pressure cycling test;
7. leak test;
8. design burst pressure test;
9. burst test.

NOTE This the standard sequence of tests defined in ECSS-E-ST-10-03. Examples of rationale for changes to this sequence are:

- Additional qualification test types (e.g. thermal) or inspection steps;
- Identified risk that for the particular design the defined sequence can be either unconservative or unnecessarily conservative.
- Omission of test types based on successful heritage or testing of engineering model.

ECSS-E-ST-32-02_0260462

d. The leak test and NDT after proof pressure test specified in 4.6.2.3c, and the final burst test, specified in 4.6.2.3c may be deleted with customer approval.

ECSS-E-ST-32-02_0260463

e. When the vibration loads are enveloped by the other qualification tests, the vibration tests specified in 4.6.2.3c may be deleted with customer approval.

ECSS-E-ST-32-02_0260306

f. NDT operations shall be applied to the over-wrap, in addition to NDT on the liner.

ECSS-E-ST-32-02_0260307

g. Clause 5.4 shall be applied to the qualification tests.

ECSS-E-ST-32-02_0260308

h. The need to apply external loads in combination with internal pressure during qualification testing shall be considered taking into account their relative magnitude, the fatigue and destabilizing effects of external loads.

NOTE This is considered, for example, for cases where locally or globally non-pressure loads are significant, and applicable yield or ultimate combined load cases are not covered by proof or burst testing, contradicting to some extent the characteristic that pressure loads are dominant, and where it is not acceptable to cover the difference by analysis, similarity, test on design detail, etc. In vibration testing the vibration loads, per axis, will actually apply the strength qualification factor of 1,25, but no factor, like FOSY or FOSU, on pressure.

ECSS-E-ST-32-02_0260309

i. If external cycling loads are applied, the load shall be cycled to limit for four times the predicted number of operating cycles of the most severe design condition.

NOTE Examples: Destabilizing load with constant minimum internal pressure or maximum additive load with a constant MDP.
The actual cycle life can be complex and is often replaced by a simplified test spectrum, of comparable severity, in the cycling test.

4.6.2.4 Acceptance tests

ECSS-E-ST-32-02_0260310

a. All hardware shall be submitted to the following sequence of tests, or alternative sequence agreed between customer and supplier:

1. initial NDT, in order to establish the initial condition of the hardware;
2. proof pressure test;
3. leak test;
4. final NDT.

NOTE For example:

- The NDT prior to proof test can be substituted for that of the manufacturing process.
- Proof test monitoring by acoustic emission is acceptable for composite items instead of post testing NDT, with customer approval. Detailed acoustic emission procedures, with proven health monitoring capability, are agreed per NDT plan, in line with the general requirements of clauses 5 and 9 of the ECSS-Q-ST-70-15.

ECSS-E-ST-32-02_0260311

b. Initial NDT operations shall be applied to the over-wrap, in addition to NDT on the liner.

ECSS-E-ST-32-02_0260312

c. Clause 5.5 shall be applied to the acceptance tests.

ECSS-E-ST-32-02_0260313

d. Final NDT shall be performed on the over-wrap of the COSPE as a minimum.

4.6.3 COSPE with homogeneous non metallic liner

4.6.3.1 Factors of safety

ECSS-E-ST-32-02_0260314

a. The values in Table 4-1 and Table 4-2 shall be applied as minimum values of factors of safety for internal pressure of composite overwrapped special pressurized equipment (COSPE).

NOTE Exceptions to the values provided in Table 4-1, Table 4-2 or ECSS-E-ST-32-10 are sometimes specified by the customer or granted with customer approval.

Examples of reasons for exceptions: ground/range safety rules, mitigation of concerns due to time dependent phenomena like creep and for composites stress rupture, human safety during the mission.

When this is the case for a burst factor, the following relations can be used for determination of the proof factor:

$j_{proof} = (1 + j_{burst}) / 2$ when $j_{burst} < 2{,}0$

j_{proof} = 1,5 when j_{burst} > 2,0

ECSS-E-ST-32-02_0260315

b. The values specified in ECSS-E-ST-32-10 for 'pressurized hardware' shall be applied as minimum values of factors of safety for loads different from internal pressure.

NOTE Exceptions to the values provided in are sometimes specified by the customer or granted with customer approval.

Examples of reasons for exceptions: ground/range safety rules, mitigation of concerns due to time dependent phenomena like creep and for composites stress rupture, human safety during the mission.

When this is the case for a burst factor, the following relations can be used for determination of the proof factor:

$j_{proof} = (1 + j_{burst}) / 2$ when $j_{burst} < 2,0$

$j_{proof} = 1,5$ when $j_{burst} \geq 2,0$

ECSS-E-ST-32-02_0260436

4.6.3.2 Development approach

ECSS-E-ST-32-02_0260316

a. Clause 5.2 on structural engineering shall be applied.

ECSS-E-ST-32-02_0260317

b. A stiffness demonstration shall be performed by analysis and test.

ECSS-E-ST-32-02_0260318

c. A strength and stability demonstration shall be performed by analysis and test.

ECSS-E-ST-32-02_0260319

d. The LBB failure mode shall be demonstrated by test using a method agreed with the customer.

NOTE Experience with non-metallic lined COSPE is limited, and LBB failure mode demonstration according to 5.3 can be difficult or not relevant (see also e and f below). No definite requirements are therefore provided in this standard on whether and how to apply clause 5.3, and specifically 5.3.4

(Demonstration of LBB by test using full-scale article).

NOTE ECSS-E-ST-32-02_0260320

e. The liner of the COSPE shall exhibit a LBB failure mode.

NOTE The fulfilment of this requirement is sometimes possible without LBB analysis or test per 5.3, for liners that do not experience significant load when compared to the overwrap. Example: thermoplastic liner, see e.g. AIAA G-082.

ECSS-E-ST-32-02_0260464

f. When the non-metallic liner of the COSPE remains in compression up to MDP and surface flaws do not propagate during the LBB test, the flaws pre-fabricated in the liner of the LBB full-scale specimen may be through cracks.

ECSS-E-ST-32-02_0260322

g. 'Safe life item' demonstration of the liner shall be performed in accordance with ECSS-E-ST-32-01:

1. by test for non-metallic items;
2. by analysis or test or both for metallic items (e.g. metallic bosses).

ECSS-E-ST-32-02_0260323

h. Qualification tests shall be conducted according to clause 4.6.3.3 to demonstrate the structural adequacy of the design.

ECSS-E-ST-32-02_0260324

i. For corrosion control and prevention, the requirements in ECSS-E-ST-32 shall apply.

NOTE ECSS-E-ST-32 refers to ECSS-Q-ST-70 and related standards.

ECSS-E-ST-32-02_0260325

j. Embrittlement control shall be applied in accordance with ECSS-E-ST-32-08.

ECSS-E-ST-32-02_0260326

k. For materials selection, material design allowables and their characterisation, requirements shall be applied in conformance with clause 5.6 and ECSS-E-ST-32.

ECSS-E-ST-32-02_0260327

l. For 'process control', requirements shall be in conformance with ECSS-Q-ST-70.

ECSS-E-ST-32-02_0260328

m. Inspections shall be applied according to clause 5.7.

NOTE The development approach is illustrated in Figure 4-5.

n. Fatigue-life demonstration shall be performed for the composite over-wrap by analysis or test or both in conformance with ECSS-E-ST-32.

4.6.3.3 Qualification tests

ECSS-E-ST-32-02_0260329

a. A first qualification test article shall be submitted to the following sequence of tests, or alternative sequence agreed between customer and supplier:

1. non-destructive testing (NDT);
2. proof pressure test;
3. leak test;
4. NDT;
5. pressure cycling test;
6. leak test;
7. design burst pressure test;
8. burst test.

NOTE This the standard sequence of tests defined in ECSS-E-ST-10-03. Examples of rationale for changes to this sequence are:

- Additional qualification test types (e.g. thermal) or inspection steps (e.g. before burst pressure testing);
- Identified risk that for the particular design the defined sequence can be either unconservative or unnecessarily conservative.
- Omission of test types based on successful heritage or testing of engineering model. Examples: pressure cycling test, burst test, NDT steps.

ECSS-E-ST-32-02_0260465

b. The first qualification test article specified in 4.6.3.3a may be deleted with customer approval.

NOTE Examples of rationale for deletion of a formal first qualification test article:

- Similarity with a qualified vessel giving confidence in the robustness of the design and manufacturing processes;
- Successful testing of a representative engineering model.
- Additional factors that can be considered: simplicity of the design, actual margins, heritage of the supplier.

ECSS-E-ST-32-02_0260331

c. A second qualification test article shall be submitted to the following sequence of tests, or alternative sequence agreed between customer and supplier:

1. NDT;
2. proof pressure test;
3. leak test;
4. NDT;
5. vibration tests;
6. pressure cycling test;
7. leak test;
8. design burst pressure test;
9. burst test.

NOTE This the standard sequence of tests defined in ECSS-E-ST-10-03. Examples of rationale for changes to this sequence are:

- Additional qualification test types (e.g. thermal) or inspection steps;
- Identified risk that for the particular design the defined sequence can be either unconservative or unnecessarily conservative.
- Omission of test types based on successful heritage or testing of engineering model.

ECSS-E-ST-32-02_0260466

d. The leak test and NDT after proof pressure test specified in4.6.3.3c, and the final burst test specified in 4.6.3.3c may be deleted with customer approval.

ECSS-E-ST-32-02_0260467

e. When the vibration loads are enveloped by the other qualification tests, the vibration tests specified in 4.6.3.3c may be deleted with customer approval.

ECSS-E-ST-32-02_0260334

f. NDT operations shall be applied to the over-wrap, in addition to NDT on the liner.

ECSS-E-ST-32-02_0260335

g. Clause 5.4 shall be applied to the qualification tests.

ECSS-E-ST-32-02_0260336

h. The need to apply external loads in combination with internal pressure during qualification testing shall be considered taking into account their relative magnitude, the fatigue and destabilizing effects of external loads.

NOTE This is considered, for example, for cases where locally or globally non-pressure loads are significant, and applicable yield or ultimate combined load cases are not covered by proof or burst testing, contradicting to some extent the characteristic that pressure loads are dominant, and where it is not acceptable to cover the difference by analysis, similarity, test on design detail, etc. In vibration testing the vibration loads, per axis, will actually apply the strength qualification factor of 1,25, but no factor, like FOSY or FOSU, on pressure.

ECSS-E-ST-32-02_0260337

i. If external cycling loads are applied, the load shall be cycled to limit for four times the predicted number of operating cycles of the most severe design condition.

NOTE Examples: Destabilizing load with constant minimum internal pressure or maximum additive load with a constant MDP.
The actual cycle life can be complex and is often replaced by a simplified test spectrum, of comparable severity, in the cycling test.

4.6.3.4 Acceptance tests

ECSS-E-ST-32-02_0260338

a. All hardware shall be submitted to the following sequence of tests, or alternative sequence agreed between customer and supplier:

1. initial NDT, in order to establish the initial condition of the hardware;
2. proof pressure test;
3. leak test;
4. final NDT.

NOTE For example:

- The NDT prior to proof test can be substituted for that of the manufacturing process.
- Proof test monitoring by acoustic emission is acceptable for composite items instead of post testing NDT, with customer approval. Detailed acoustic emission procedures, with proven health monitoring capability, are agreed per NDT plan, in line with the general requirements of clauses 5 and 9 of the ECSS-Q-ST-70-15.

ECSS-E-ST-32-02_0260339

b. Initial NDT operations shall be applied to the over-wrap, in addition to NDT on the liner.

ECSS-E-ST-32-02_0260340

c. Clause 5.5 shall be applied to the acceptance tests.

ECSS-E-ST-32-02_0260341

d. Final NDT shall be performed on the over-wrap of the COSPE as a minimum.

5
Specific requirements

5.1 Overview

This clause presents the detail of requirements used in the development approach, qualification and acceptance of pressurized hardware.

These requirements are specific requirements in the sense that their applicability depends on the category of pressurized hardware, as presented in clauses 4.2.5 to 4.6.

The following requirements are included:

- structural engineering;
- failure mode demonstration;
- damage control of pressurized composite hardware;
- qualification tests;
- acceptance tests;
- composite over-wrap material characterisation;
- inspection.

5.2 Structural engineering

ECSS-E-ST-32-02_0260342

a. The structural design and verification of pressurized hardware shall be in conformance with ECSS-E-ST-32.

NOTE 1 Some structural topics are not explicitly addressed in this standard because they are addressed in ECSS-E-ST-32, which addresses for example: Verification by analysis (4.6.2), including modelling aspects (4.6.2.2, including correlation, with DRD); Material design allowables (4.5.8); Deliverables (4.10, including structural reports, with DRDs).

NOTE 2 Some qualification and acceptance tests can be driven by the ECSS-E-ST-32 (and not necessarily by ECSS-E-ST-10-03 which does not cover fully the structural subsystem) for items which are significantly structurally loaded by non-pressure loads. Example: A composite skirt fulfils as well ECSS-E-ST-32 clause 4.6.4, which requests an acceptance test to limit load, unless agreed

otherwise. Also, ECSS-E-ST-10-03 states that a structural proof test can be considered for pressure vessel if not covered by higher level test (e.g. sinusoidal with full tanks).

NOTE 3 Some related ECSS standards limit the scope of applicability of the ECSS-E-ST-32-02 to particular types of pressurized hardware. Examples:

- The scope of ECSS-E-ST-32-02 states that solid propellant motor cases are not covered by this standard. These are addressed by ECSS-E-ST-35-02.
- ECSS-E-ST-35-03, subclause 9.6 on mechanical design.

ECSS-E-ST-32-02_0260343

b. The effect of each operating parameter of the system and any external loads and environments shall be considered for MDP determination.

NOTE Examples of these parameters are pressure regulator lock-up characteristics, valve actuation and water hammer.

ECSS-E-ST-32-02_0260344

c. Proof pressure and design burst pressure shall be derived from the MDP using the factor of safety given in clause 4.

NOTE ECF in accordance with 5.4.1.c or 5.5.1.b apply as well.

ECSS-E-ST-32-02_0260345

d. The range of internal pressure shall be taken into account in the stiffness analysis .

NOTE Example of such an analysis is a natural frequency analysis.

ECSS-E-ST-32-02_0260346

e. As a minimum, any item of pressurized hardware shall possess, throughout the respective service life of the hardware in the expected operating environments, positive margin of safety, in conformance with ECSS-E-ST-32, considering the following:

1. proof pressure is withstood without detrimental deformation;
2. design burst pressure is withstood without experiencing rupture or fibre failure;
3. combined loads are evaluated using the following safety factors per clause 4.2.6 of ECSS-E-ST-32:

(a) those defined in Table 4-6 of ECSS-E-ST-32-10 for all load contributors, excluding internal pressure and relieving load components;

(b) those defined in clause 4 for internal pressure;

(c) no safety factor for relieving loads.

NOTE Examples, a non-exhaustive list, of load combinations to be evaluated:

- DYL and simultaneous internal pressure multiplied by FOSY for internal pressure ;
- MDP multiplied by FOSY for internal pressure and simultaneous loads, multiplied by FOSY for mechanical and thermal loads;
- DUL and simultaneous internal pressure multiplied by FOSU for internal pressure;
- MDP multiplied by FOSU for internal pressure and simultaneous loads multiplied by FOSU for mechanical and thermal loads;
- DUL and simultaneous external pressure multiplied by FOSU for mechanical and thermal loads;
- If the load cases described above are not enveloping the most critical applicable load interaction, it can be appropriate to evaluate more load combinations. MDP is defined in terms of absolute internal pressure, whereas for hardware where pressurized compartments interact it can be appropriate to use pressure differential or gauge pressure.

ECSS-E-ST-32-02_0260347

f. The minimum internal pressure to guaranty structural stabilization shall be identified and included in the acceptance data package.

ECSS-E-ST-32-02_0260348

g. The pressurized hardware shall possess, throughout its service life in the expected operating environments, a stability such to withstand:

1. DUL and simultaneous external pressure multiplied by FOSU for pressure loads, without experiencing collapse when pressurized to the minimum anticipated operating pressure;
2. DUL and simultaneous internal pressure without experiencing collapse.

ECSS-E-ST-32-02_0260349

h. A scatter factor of five (5) shall be used in fatigue analysis.

NOTE This is considered equivalent to allowing a maximum cumulative fatigue damage of 0,8 using a scatter factor 4, as defined in other standards.

i. Limit loads, design limit loads and associated load cases shall be defined, in agreement with the customer.

NOTE 1 Refer to ECSS-E-ST-32C, 4.2.7 and 4.2.8.

NOTE 2 This includes definition of MEOP and MDP values (see definitions in ECSS-E-ST-32C). Note that MDP includes Km and Kp, but not Kq, KMP and KLD, also when applying the Satellite Test Logic of Figure 4-1 of ECSS-E-ST-32-10C.

NOTE 3 MEOP or MDP can be specified by the customer, or derived, for example, from an analysis of the pressurized system.

NOTE 4 MDP is equal to or larger than MEOP. Via the factors Kp and Km, MDP accounts for uncertainties that are not already accounted for in MEOP. ECSS-E-ST-32-10C mentions a typical Km of 1,0 for internal pressure loads for pressurized hardware. Note that a different Km>1 can apply to the finite element analysis of the pressurized hardware, especially for verification of non-pressure loads.

NOTE 5 Fault tolerance requirements are sometimes specified by the customer for MEOP.

NOTE 6 Different components and locations in a pressurized system can have different MEOPs and MDPs. For example, due to pressure transient peaks, barriers, regulators.

NOTE 7 Historically the MDP definition of ECSS-E-ST-32 can differ from other standards, and it is difficult to achieve full consistency. Example: MDP in NASA standards or similar are equivalent to MEOP per ECSS-E-ST-32 definition (including fault tolerance)

j. The strength verification of the pressurized hardware shall take into account variations of the material properties as a function of time and environment under sustained loading, using methodology agreed with the customer.

NOTE This includes effects of ageing, creeping and stress rupture.
Creep can occur at relatively low temperatures in for example: polymeric matrix and adhesive materials and organic fibres, like aramid fibres. Creep in matrix or fibres can trigger stress rupture. Additional information on stress rupture can be found in NASA/SP-2011-573, ANSI/AIAA S-081B-2018, AFSPCMAN 91-710, etc.

5.3 LBB failure mode demonstration

5.3.1 General

ECSS-E-ST-32-02_0260350

a. <<deleted>>

ECSS-E-ST-32-02_0260351

b. The choice of the demonstration methodology, analysis or test or both, shall conform to the requirements on LBB failure mode demonstration specified in clauses 4.2 to 4.5 according to the type of pressurized hardware.

NOTE For example:

- Failure mode may be demonstrated by similarity with an existing analysis or test with customer approval.
- For new designs, without heritage, the demonstration by test is sometimes specified by the customer.

ECSS-E-ST-32-02_0260352

c. When LBB failure mode is demonstrated by test, coupons, sub-scale or full-scale articles with prefabricated flaws shall be used as test specimens, in accordance with ECSS-E-ST-32-01.

NOTE Requirement 6.3.1.b of ECSS-E-ST-32-01 specifies that the methodology applied for evaluation by test is subject to customer approval.

ECSS-E-ST-32-02_0260353

d. The LBB failure mode shall be demonstrated for the structural items of the pressurized hardware, which serve as a fluid permeation barrier and which are primarily designed by pressure loads.

NOTE For example:

- For composite over-wrapped pressurized hardware, the liner is the fluid permeation barrier.
- For composite over-wrapped pressurized hardware, the boss area can be primarily designed by shear.
- For CPV and CPS, the composite wall itself is considered as the fluid permeation barrier.

ECSS-E-ST-32-02_0260354

e. When the LBB failure mode demonstration is performed for metallic items, fracture mechanics principles shall be employed, in accordance with ECSS-E-ST-32-01.

ECSS-E-ST-32-02_0260355

f. Areas where the LBB failure mode is not demonstrated shall be designed according to safe-life requirements as per ECSS-E-ST-32-01.

ECSS-E-ST-32-02_0260356

g. For composite and composite over-wrapped pressurized hardware, potential degradation of the composite strength by the leaking fluid shall be accounted for in the failure mode demonstration.

5.3.2 Demonstration of LBB by analysis

ECSS-E-ST-32-02_0260357

a. It shall be shown that, at MDP, an initial surface crack with a flaw shape (a/c), ranging from 0,2 to 1,0, meets the following conditions:

1. it does not fail as a surface crack; and
2. it grows through the wall of the hardware to become a through crack with a length greater than or equal to 10 times the wall thickness of the metallic hardware item and remains stable.

NOTE For example:

- For a part-through surface crack, the crack aspect ratio is the ratio (a/c) of crack depth (a) to half crack length (c). For a part-through corner crack, the crack aspect ratio is the ratio (a/c) of crack depth (a) to crack length (c)/
- If no assumption is made about the initial surface crack size, the specified range a/c between 0,2 and 1,0 leads to a maximum through crack length of 2 c = 10 t (for a = t, where t is the wall thickness).

ECSS-E-ST-32-02_0260358

b. When LBB demonstration is based on a through crack with a length less than 10 times the wall thickness in accordance with 5.3.2a.2, the considered initial crack size shall be justified.

NOTE Justification of initial surface crack size can be based on NDT capability or on a crack whose depth is as close as possible to the wall thickness, within the range of a/c specified in clause 5.3.2a.

5.3.3 Demonstration of LBB by test using coupons

ECSS-E-ST-32-02_0260359

a. Coupons shall duplicate the materials and the thickness of the metallic hardware items.

NOTE Materials addressed include parent metals, weld joints, and heat affected zones.

ECSS-E-ST-32-02_0260360

b. The coupon tests shall duplicate the loading conditions of the metallic hardware items.

NOTE Loading conditions include stress state aspects of bi-axial, compressive stresses parallel to crack plane.

ECSS-E-ST-32-02_0260361

c. The flaws shall be surface cracks and the flaw shape of the pre-fabricated surface cracks shall range from a/c = 0,2 to 1,0.

NOTE For the definition of a part-through surface crack, and a part-through corner crack see NOTE 1 in 5.3.2a.

ECSS-E-ST-32-02_0260362

d. The initial surface crack size shall be justified.

NOTE Justification of initial surface crack size can be based on NDT capability or on a crack whose depth is as close as possible to the wall thickness, within the range of a/c specified in 5.3.3c.

ECSS-E-ST-32-02_0260363

e. Stress (or strain) cycles shall be applied to the specimens with the maximum stress (or strain) corresponding to the MDP level and minimum stress (or strain) kept to zero, or actual minimum stress (or strain), until the surface crack grows through the specimen's thickness to become a through crack.

ECSS-E-ST-32-02_0260364

f. It shall be shown that the length of the through crack becomes equal to or greater than 10 times the specimen's thickness and remains stable at MDP.

5.3.4 Demonstration of LBB by test using full-scale or sub-scale article

ECSS-E-ST-32-02_0260365

a. The full-scale or sub-scale article shall be representative of the flight hardware.

ECSS-E-ST-32-02_0260366

b. The type and initial size of pre-fabricated flaws shall be justified.

NOTE Justification of initial flaw size can be based on NDT capability or on a crack whose depth is as close as possible to the wall thickness, within the range of a/c specified in sub clause 5.3.4c.

ECSS-E-ST-32-02_0260367

c. For pre-flawed metallic items, the flaws shall be surface cracks and the aspect ratio of the pre-fabricated surface cracks shall range from a/c = 0,2 to 1,0.

NOTE For the definition of a part-through surface crack, and a part-through corner crack see NOTE 1 in 5.3.2a.

ECSS-E-ST-32-02_0260468

d. For pre-flawed composite items (liner or walls), the flaws may be through cracks with a length greater than or equal to 10 times the wall thickness of the item, if agreed between customer and supplier.

ECSS-E-ST-32-02_0260369

e. Location and orientation of pre-fabricated flaws shall be the most critical with regard to LBB response.

ECSS-E-ST-32-02_0260370

f. Pressure cycles shall be applied to the pressurized hardware, with the upper pressure equal to MDP and the lower pressure greater than or equal to zero.

ECSS-E-ST-32-02_0260371

g. After a flaw has grown through the thickness to become a through flaw and leakage has been detected, internal pressure shall be increased up to MDP.

ECSS-E-ST-32-02_0260372

h. At least one of the following conditions shall be satisfied after 5.3.4g has been met:

— no burst occurs at MDP and leak rate is equal to or greater than a value defined with customer approval. This criteria is applicable to composite over-wrapped pressurized hardware, or

— the length of the through crack in the item becomes equal to or greater than 10 times the wall thickness of the item and remains stable at MDP. This criteria is only applicable to metallic and fully composite pressurized hardware.

ECSS-E-ST-32-02_0260373

i. Test fluid shall be compatible with the materials used in the hardware and not pose a hazard to test personnel.

ECSS-E-ST-32-02_0260374

j. The full-scale test shall duplicate the loading conditions and pressurization medium (gas or liquid) of the flight hardware.

NOTE E.g. loading conditions include stress state aspects of bi-axial, compressive stresses parallel to crack plane.

5.3.5 Report of LBB demonstration

ECSS-E-ST-32-02_0260375

a. When LBB is demonstrated by analysis an analysis report in conformance with ECSS-E-ST-32, Annex E, Fracture control analysis, shall be prepared, including a description of the loading spectra, assumed initial flaw sizes, crack growth models, and fatigue crack growth rates.

ECSS-E-ST-32-02_0260376

b. When LBB is demonstrated by test, a test report shall be prepared in conformance with ECSS-E-ST-10-02.

5.4 Qualification tests

5.4.1 General

ECSS-E-ST-32-02_0260377

a. ‘General requirements’ and ‘Qualification testing’ requirements shall apply in conformance with ECSS-E-ST-10-03.

NOTE 1 According to Table 5-1 of ECSS-E-ST-10-03 the following tests can apply for qualification of pressurized hardware (categories c-f):

- Functional and performance

- Humidity
- Life (if not covered by pressure cycling test)
- Burn-in
- Physical properties
- Static load, Spin, Sine burst
- Random, acoustic, sine vibration and shock
- Pressure testing (as addressed in 5.4.1)
- Micro-vibration generated environment
- Thermal testing
- Various Electrical / RF (incl. bonding)
- Audible noise

Only the tests that are most relevant in practice for the structural verification of the pressurized shell are explicitly addressed in this pressurized hardware standard.

NOTE 2 Pressurization rates and hold times during qualification testing are not always specified in this standard. Deviation from mission representative test conditions are agreed between customer and supplier, in line with ECSS-E-ST-10-03.

ECSS-E-ST-32-02_0260378

b. When the hardware mounting induces axial or radial restrictions on the pressure driven expansion of the hardware, the pressure test fixture shall simulate the structural response or reaction loads of the flight mounting.

ECSS-E-ST-32-02_0260379

c. When a qualification test is conducted in environment other than the environment expected for the design loads, the impact of the change of material properties in this environment shall be taken into account by adjustment of the pressure and load level by an ECF agreed by the customer.

NOTE Application of ECF is in line with clause 4.6.3.2.f of ECSS-E-ST-32 and also ECSS-E-ST-10-03.
Examples:
Design Burst Pressure = BF x ECF_{burst} x MDP
Proof Pressure = Proof Factor x ECF_{proof} x MDP
Cycling test pressure = $ECF_{cycling}$ x pressure
Environmental effects considered include, but are not limited to, those induced by temperature, and humidity.
The applied test loading is factored up to take account of the environmentally induced degradation of the material properties and/or environmentally induced loadings (e.g.

thermoelastic induced loads). Test factors less than one are not applied unless explicitly justified and agreed with the customer.
The magnitude of the applied ECF is based on reliable and applicable material data. Where such data does not exist, dedicated samples or sub-scale articles are manufactured and tested to define representative material property relationships. Sometimes no convenient test environment nor ECF can be defined, for example due to high gradients in strength or temperature, and an alternative approach is agreed between customer and supplier.

ECSS-E-ST-32-02_0260380

d. When NDT is performed in the qualification tests, it shall meet clause 5.7.

ECSS-E-ST-32-02_0260381

e. The test fluids shall not deteriorate the test article.

ECSS-E-ST-32-02_0260382

f. The test fluids shall not pose a hazard to the test personnel.

ECSS-E-ST-32-02_0260383

a. When the strength properties of the materials depend on the fluid to be stored in the flight hardware, this specific fluid shall be used to pressurize the qualification test articles if the effect of the fluid cannot be addressed by an ECF as defined in 5.4.1.c.

NOTE For example when the stored fluid is liquid hydrogen.

ECSS-E-ST-32-02_0260384

b. In case of changing the manufacturing process, the qualification tests shall be repeated unless it is demonstrated that the new manufacturing process maintains or improves material and geometrical characteristics.

NOTE For example, CMH-17-1G, Vol. 1, section 8.4.1 addresses equivalence criteria for composite material.

c. Omission of dedicated qualification test hardware shall be based on

1. similarity to a previously tested qualification model that is sufficiently similar in design, processing, installation configuration, and required test loading, and
2. on documented rationale approved by the customer.

NOTE 1 The rationale can also address qualification gaps of the heritage hardware versus the new specification, which is covered by for example PFM testing.

NOTE 2 For additional guidance on verification by similarity, see ECSS-E-ST-10-02 (clause 5.2.2.3), and for example AIAA S-110A (TBC), ATR-2005(5128)-1, NASA/SP-2011-573.

d. Pressurized hardware shall be instrumented during qualification testing in order to provide engineering data for validation of dynamic behaviour and structural margins of safety.

NOTE The type and amount of instrumentation required typically depends on the criticality of the phenomena. Examples:
Pressure vessel with low margin on burst factor 1.5 typically requires more instrumentation than simple equipment with generous margin on burst factor 2.5.
Dynamic loads can be more or less sensitive to variation in natural frequency.
The model will typically describe the performance of the hardware with minimum characteristics, whereas this is typically not the case for the hardware subjected to the qualification testing, therefore the performance of the tested hardware is typically better than that predicted by the model.

5.4.2 Proof pressure test

ECSS-E-ST-32-02_0260385

a. During the proof pressure test, the load level shall be maintained for 5 minutes as a minimum.

NOTE The proof pressure test load level includes pressure level and external load level.

ECSS-E-ST-32-02_0260386

b. External loads in combination with internal pressures during proof testing during qualification shall be applied, unless based on evaluation of the relative magnitude, the destabilizing effect, or both, of stresses due to the external load it can be justified that this is not significant for the verification by test of structural margins.

c. The pressurized hardware shall not leak, rupture, or experience detrimental deformation during the proof test.

5.4.3 Leak test

ECSS-E-ST-32-02_0260387

a. During the leak test, the pressure level shall be maintained at MDP or greater for a duration which is sufficient to ensure leakage rates are both stable and reliably measured.

NOTE ECSS-E-ST-10-03 requests that the pressure is maintained for 30 minutes as minimum. Further requirements on leak testing can be found in ECSS-Q-ST-70-15. Further guidance can be found in ECSS-E-HB-10-03A. The duration necessary for stable leak rates to be achieved from composite overwrapped vessels is sensitive to the overwrap properties (e.g. thickness, matrix cracking) Also, it can take time for liquid residue from prior testing to clear a leak path.

ECSS-E-ST-32-02_0260388

b. For qualification 'leak test', requirements shall be in conformance with ECSS-E-ST-10-03.

NOTE Exceptions to the values provided in 5.4.3a and 5.4.3b are sometimes specified by the customer or granted with customer approval.

5.4.4 Vibration test

ECSS-E-ST-32-02_0260389

a. Vibration testing shall be conducted in accordance with ECSS-E-ST-10-03 at the most critical combination or combinations of pressure condition and vibration environment.

NOTE Adequate coverage of critical criteria (e.g. strength, stability, natural frequencies, cavitation) can necessitate repeating vibration tests at more than one internal pressure. In many cases the proof test scopes the structural integrity of the pressurized shell and vibration testing can be performed at a reduced pressure. For example, system test at low pressure ('empty tank testing') can be specified.

ECSS-E-ST-32-02_0260390

b. Operational conditions (e.g. fluid density, and filling ratio) shall be taken into account in the test configuration.

5.4.5 Pressure cycling test

ECSS-E-ST-32-02_0260426

a. Pressure cycling shall be performed for four times the number of pressure cycles in one service life and include at least 50 cycles ranging from zero differential pressure to MDP or higher and back to zero differential pressure.

ECSS-E-ST-32-02_0260427

b. Only cycles having a peak operating pressure that creates a liner tensile stress shall be considered in the life cycle test of composite over-wrapped pressurized hardware.Liner tensile stress is created when the stress created by the pressure exceeds the compressive metal liner pre-stress imposed by the over-wrap, as a result of vessel autofrettage.

c. Pressure cycles of the service life that are not ranging from zero differential pressure to MDP or higher and back to zero differential pressure can be grouped and replaced by a number of pressure cycles which have the same or higher maximum pressure and pressure range causing at least the same fatigue damage.

d. If material property changes due to temperature cannot be reasonably captured via an ECF then this testing shall be performed at the worst-case operating temperature.

NOTE 1 The service life includes all phases of the tank life spectrum, i.e. equipment and higher level testing, tank loading, launch, in-flight cycles etc. Contingency cycles are included if necessary.

NOTE 2 If a tank (typically a COPV) is subjected to an autofrettage cycle prior to acceptance testing, the life factor four is not applied to this cycle in the pressure cycling test. ECSS-E-ST-32-01C (7.2.8.j) requires that for the autofrettage cycle the maximum possible crack growth shall be considered in the safe life calculation unless adequate NDT is possible afterwards.

NOTE 3 to item d Application of ECF is in line with clause 4.6.3.2.f of ECSS-E-ST-32 and also ECSS-E-ST-10-03.

5.4.6 Design burst pressure test

ECSS-E-ST-32-02_0260391

a. During the design burst pressure test, the design burst pressure level shall be maintained for 30 seconds as a minimum.

ECSS-E-ST-32-02_0260392

b. No structural failure, collapse shall occur prior to the end of the design burst pressure application.

NOTE 1 If leakage occurs during the design burst pressure test, above the proof pressure, the acceptability will be agreed between customer and supplier.

NOTE 2 According to ECSS-E-ST-10-03, after burst pressure, no space segment equipment or any of its parts is used for further qualification activities or as flight hardware.

5.4.7 Burst test

ECSS-E-ST-32-02_0260393

a. The pressure shall be increased until burst occurs.

ECSS-E-ST-32-02_0260394

b. The burst pressure shall be recorded.

5.5 Acceptance tests

5.5.1 General

ECSS-E-ST-32-02_0260395

a. 'General requirements' and 'Acceptance testing' requirements shall apply in conformance with ECSS-E-ST-10-03.

NOTE 1 According to Table 5-3 of ECSS-E-ST-10-03 the following tests can apply for acceptance of pressurized hardware (categories c-f):

- Functional and performance
- Burn-in
- Physical properties
- Static load
- Random vibration
- Leak and proof
- Micro-vibration generated environment
- Thermal testing
- Various Electrical / RF (incl. bonding)
- Audible noise

Only the tests that are most relevant in practice for the structural verification of the pressurized shell are explicitly addressed in this pressurized hardware standard.

NOTE 2 Pressurization rates and hold times during qualification testing are not always specified in this standard. Deviation from mission representative test conditions are agreed between customer and supplier, in line with ECSS-E-ST-10-03.

ECSS-E-ST-32-02_0260396

b. When an acceptance test is conducted in environment other than the environment expected for the design loads, the impact of the change of material properties in this environment shall be taken into account by adjustment of the pressure and load level by an ECF agreed by the customer.

NOTE Application of ECF is in line with clause 4.6.3.2.f of ECSS-E-ST-32 and also ECSS-E-ST-10-03.
Examples:
Proof Pressure = Proof Factor x ECFproof x MDP
Environmental effects considered include, but are not limited to, those induced by temperature, and humidity.
The applied test loading is factored up to take account of the environmentally induced degradation of the material properties and/or environmentally induced loadings (e.g. thermoelastic induced loads). Test factors less than one are not applied unless explicitly justified and agreed with the customer.
The magnitude of the applied ECF is based on reliable and applicable material data. Where such data does not exist, dedicated samples or sub-scale articles are manufactured and tested to define representative material property relationships. Sometimes no convenient test environment nor ECF can be defined, for example due to high gradients in strength or temperature, and an alternative approach is agreed between customer and supplier.

ECSS-E-ST-32-02_0260397

c. When NDT is performed in the acceptance tests, it shall meet clause 5.7.

ECSS-E-ST-32-02_0260398

d. When the strength properties of the materials depends on the fluid to be stored in the flight hardware, this specific fluid shall be used to pressurize the test articles during acceptance testing if the effect of the fluid cannot be addressed by an ECF as defined in 5.5.1.b.

NOTE For example when the stored fluid is liquid hydrogen.

5.5.2 Proof pressure test

ECSS-E-ST-32-02_0260399

a. During the proof pressure test, the load level (i.e. pressure level, external load level) shall be maintained for 5 minutes as minimum.

ECSS-E-ST-32-02_0260400

b. External loads in combination with internal pressures during proof testing during acceptance shall be applied, unless evaluated based on evaluation of the relative magnitude, the destabilizing effect, or both, of stresses due to the external load it can be justified that this is not significant for the verification by test of structural margins.

NOTE This is considered, for example, for cases where locally or globally non-pressure loads are significant, contradicting to some extent the characteristic that pressure loads are dominant, and where it is not accepted to omit the difference during acceptance testing. For instance: This can avoid inadequate flaw screening of welds, which are not covered by adequate NDT, during acceptance testing.

c. The pressurized hardware shall not leak, rupture, or experience detrimental deformation during the proof test.

5.5.3 Leak test

ECSS-E-ST-32-02_0260401

a. During the leak test, the pressure level shall be maintained at MDP or greater for a duration which is sufficient to ensure leakage rates are both stable and reliably measured.

NOTE ECSS-E-ST-10-03 requests that the pressure is maintained for 30 minutes as minimum. Further requirements on leak testing can be found in ECSS-Q-ST-70-15. Further guidance can be found in ECSS-E-HB-10-03. The duration necessary for stable leak rates to be achieved from composite overwrapped vessels is sensitive to the overwrap properties (e.g. thickness, matrix cracking) Also, it can take time for liquid residue from prior testing to clear a leak path.

ECSS-E-ST-32-02_0260402

b. For acceptance 'leak test', requirements shall be in conformance with ECSS-E-ST-10-03.

NOTE Exceptions to the values provided in 5.5.3a and 5.5.3b are sometimes specified by the customer or granted with customer approval.

5.6 Composite over-wrap material characterization

ECSS-E-ST-32-02_0260403

a. Strength design allowable for the applicable environment shall be generated from at least one of the following tests:

1. elementary testing on samples or coupons, which are verified to be representative of the characteristics of the hardware;
2. bursting of full or sub-scale specimens of different configurations, provided that applicability to the full scale article is demonstrated by analysis or testing;
3. bursting of sub-scale specimens, provided that scaling factor is accounted for and verified;
4. bursting of full-scale specimens.

NOTE The requirement asks for a demonstration that the allowables capture the scatter in properties of the actual composite hardware. Either directly or by means of e.g. scaling. Further guidance can be found in AIAA S-081 (for COPV) and more generally in CMH-17.

ECSS-E-ST-32-02_0260404

b. Test results from at least two lots of yarns shall be used in the design allowable calculations unless all of the items are fabricated from the same lot of material.

NOTE This standard refers to ECSS-E-ST-32 for the definition of allowables. 4.5.8.d and e of ECSS-E-ST-32 address the need for evaluation of the variations from batch to batch. Further guidance can be found in volume 1 of CMH-17, for example see section 8.4.4, Modified coefficient of variation approach, to address the fact that scatter observed during material qualification and allowables generation programs does not fully capture the true material property variability.

ECSS-E-ST-32-02_0260405

c. When the composite wall of the pressurized hardware serves partially or totally as a permeation barrier (e.g. for CPV or CPS), any degradation of the wall due to the contact with the stored fluid shall be accounted for in the design allowable of material strength.

NOTE When in contact with liquid hydrogen, the composite wall can experience superficial micro-cracking and degradation of its transverse shear and tensile strength.

5.7 Inspection

5.7.1 General

ECSS-E-ST-32-02_0260406

a. An inspection plan shall be established prior to the start of fabrication.

ECSS-E-ST-32-02_0260407

b. For 'Inspection' plan, requirements shall be in conformance with ECSS-Q-ST-20 and ECSS-Q-ST-70-15.

NOTE ECSS-Q-ST-20, clause 5.5.8, addresses inspection in general, in the context of the manufacturing plan or flow chart. ECSS-Q-ST-70-15 addresses the more specific NDT plan(s).

ECSS-E-ST-32-02_0260408

c. For 'Inspection of PFCI', requirements shall be in conformance with ECSS-E-ST-32-01 and ECSS-Q-ST-70-15.

NOTE ECSS-E-ST-32-01 provides general fracture control requirements. ECSS-Q-ST-70-15, clause 9, provides the detailed inspection requirements.

ECSS-E-ST-32-02_0260409

d. The inspection plan shall specify inspection points throughout the program, beginning with material procurement, continuing through fabrication, assembly, acceptance proof test and operation, and using the following techniques:

1. procurement of raw materials, in conformance with ECSS-Q-ST-70;
2. procurement of mechanical parts in conformance with ECSS-Q-ST-70;

3. NDT for detecting mechanical damage or flaw, in conformance with clause 5.7.2 and ECSS-E-ST-32-08, ECSS-E-ST-32-01 and ECSS-Q-ST-70-15.

NOTE Clause 5.7.2 addresses composite over-wraps and composites specifically. ECSS-E-ST-32-08, 4.6.5 addresses inspection in general. ECSS-E-ST-32-01 provides general fracture control requirements, including on inspection. ECSS-Q-ST-70-15 provides more detailed requirements on non-destructive testing and inspection.
Additional information on composite and lined hardware is available in ASTM E2981 (Composite Overwraps) and ASTM E2982 (Thin-Walled Metallic Liners).

ECSS-E-ST-32-02_0260410

e. Acceptance and rejection criteria shall be established within the inspection plan for each phase of inspection and for each type of inspection.

ECSS-E-ST-32-02_0260411

f. For 'Detected defects' outside of the acceptance criteria defined in 5.7.1e, requirements shall be in conformance ECSS-E-ST-32-01.

5.7.2 Inspection techniques for composite over-wraps and composites

ECSS-E-ST-32-02_0260412

a. After application of composite manufacturing process, any composite over-wrapped or composite item of pressurized hardware shall be subjected to the following inspections:

1. visual inspection for detecting impact damage,
2. state-of-the-art NDT techniques for inspecting mechanical damage or flaw induced on the composite.

NOTE This support the damage control measures addressed in clause 4.2.3.1.i. Visual inspection is generally repeated until the hardware is no longer accessible for mechanical damage.

ECSS-E-ST-32-02_0260413

b. Visual inspection shall be performed by inspectors, qualified and certified in accordance with ECSS-Q-ST-70-15, who have been trained to detect visible damage on composite or composite over-wrapped pressurized hardware involving the use of actual damaged representative hardware.

NOTE ECSS-Q-ST-70-15 clause 5, addresses NDT personnel qualification and certification. Safety authorities sometimes request specific training, for example similar to JSC-CN-24028. Additional guidance can be found in AIAA S-081, latest issue.

ECSS-E-ST-32-02_0260414

c. The NDT procedures are based on using multiple NDT methods to perform survey inspections or diagnostic inspections as follows:

1. survey NDT inspections shall be conducted when the location of the potential damage or flaw zone is unknown;

2. diagnostic NDT inspections shall be performed within a localized suspect zone to characterize the type and extent of the damage or flaw.

ECSS-E-ST-32-02_0260415

d. All NDT techniques, whether used as a single inspection technique or as a combination of methods, shall have the capability to detect impact or flaw that can cause the composite over-wrapped or composite pressurized hardware to fail to meet its requirements.

ECSS-E-ST-32-02_0260416

e. For 'NDT for composite and bonded parts', requirements shall be in conformance with ECSS-E-ST-32-01 and ECSS-Q-ST-70-15.

NOTE ECSS-E-ST-32-01 provides general fracture control requirements. ECSS-Q-ST-70-15 clause 9.3, provides the detailed inspection requirements for composite and bonded PFCI.

Bibliography

ECSS-S-ST-00	ECSS system - Description, implementation and general requirements
ECSS-E-ST-35-02	Space engineering - Solid propulsion for spacecrafts and launchers
ECSS-E-ST-35-03	Space engineering - Liquid propulsion for launchers
ECSS-Q-ST-70-80	Space product assurance - Processing and quality assurance requirements for metallic powder bed fusion technologies for space applications
AEROSPACE REPORT NO. ATR-2005(5128)-1	Operational Guidelines for Spaceflight Pressure Vessels (The Aerospace Corporation, 2005)
AFSPCMAN 91-710	Range Safety User Requirements Manual (USAF)
AIAA G-082-2022	Guide: Space Systems - Composite Overwrapped Pressure Vessels with a Plastic Liner
AIAA S-110A Refer to 'latest version'	Space Systems — Structures, Structural Items, and Pressurized structures
ANSI/AIAA S-080A-2018	Space Systems - Metallic Pressure Vessels, Pressurized Structures, and Pressure Components
ANSI/AIAA S-081B-2018	Space Systems - Composite Overwrapped Pressure Vessels
ASTM E2981-15	Standard Guide for Nondestructive Testing of the Composite Overwraps in Filament Wound Pressure Vessels Used in Aerospace Applications
ASTM E2982-14	Standard Guide for Nondestructive Testing of the Thin-Walled Metallic Liners in Filament Wound Pressure Vessels Used in Aerospace Applications
CMH-17-1G, Vol. 1	Composite Materials Handbook - Volume 1. Polymer Matrix Composites Guidelines For Characterization Of Structural Materials (SAE, 2012)
CSG-NT-SBU-16687-CNES	CSG Payload Safety Handbook, iss.2 (CNES, 2022)
JSC 66901	Damage Threat Assessment (DTA) and Damage Control Plan (DCP) Template for Composite Overwrapped Pressure Vessels (NASA, 2016)
JSC 65828 Rev. B, change 1	Structural Design Requirements And Factors Of Safety For Spaceflight Hardware (NASA, 2014)
JSC-CN-24028	Inspection for Damage to Carbon/Epoxy Composite Overwrapped Pressure Vessels (NASA, 2010) See: https://ntrs.nasa.gov/citations/20110014357
NASA/SP-2011-573	Composite Overwrapped Pressure Vessels, A Primer (NASA, 2011)
NASA-STD-5019A	Fracture Control Requirements For Spaceflight Hardware
NASA/TM−20210022275	Treatment of Transient Pressure Events in

	Space Flight Pressurized Systems (NASA, 2021)