



# **Space engineering**

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## **Fracture control**

**ECSS Secretariat  
ESA-ESTEC  
Requirements & Standards Division  
Noordwijk, The Netherlands**

## Foreword

This Standard is one of the series of ECSS Standards intended to be applied together for the management, engineering, product assurance and sustainability in space projects and applications. 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-32-01 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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ECSS-E-ST-32-01B	Never issued
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ECSS-E-ST-32-01C Rev. 1 6 March 2009	Second issue revision 1
ECSS-E-ST-32-01C Rev. 2 30 July 2021	<p>Second issue revision 2</p> <p>Changes with respect to ECSS-E-ST-32-01C Rev.1 (6 March 2009) are identified with revision tracking.</p> <p>Main changes</p> <ul style="list-style-type: none"> <li>• Implementation of change requests</li> <li>• Replacement of term “non-destructive inspection (NDI)” by “non-destructive testing (NDT)” in the whole document in accordance with ECSS-Q-ST-70-15</li> <li>• Update of Scope</li> <li>• Removal of information about the NASA Space Shuttle program (STS)</li> <li>• Update of Normative References and Terms, definitions and abbreviated terms</li> <li>• Addition of Nomenclature</li> <li>• Updates in clauses 5 and 6, to improve consistency and make the scope more generic. Removal of critical hazards from the scope, unless by customer request. Figures updated and moved where appropriate</li> <li>• 6.3.5.3.1.a.5 deleted because it reflected normal practice that does not need a dedicated requirement</li> <li>• Update of clause 7.2.5 “Derivation of material data” for the case of limited available test data</li> <li>• Update of clause 8.2 “Pressurized hardware” to clarify in more detail the existing approach and its limitations</li> <li>• Update of clause 8.2.5 “Low risk sealed containers” in line with current NASA requirements for ISS and Exploration</li> <li>• Addition of clause 8.2.7 “Pressurized components with non-</li> </ul>

	<p>hazardous LBB failure mode”</p> <ul style="list-style-type: none"> <li>• Addition of clause 8.9 “Alloys treated with electric discharge manufacturing (EDM)”</li> <li>• Addition of clause 11.2.2.5 “Safe life composite, bonded and sandwich structures”</li> <li>• Addition of clause 11.2.2.6 “Metallic parts classified as PFCI according to 11.2.2.1”</li> <li>• Addition of clause 11.2.2.7 “Fasteners classified as PFCI according to 11.2.2.1”</li> <li>• Addition of clause 11.2.2.8 “NDT of fusion welded joints in pressure components, as per 10.3.1p”</li> <li>• Several clauses and requirements moved to ECSS-Q-ST-70-15. This affects in particular clause 10</li> </ul> <p><b>Detailed Change Record:</b></p> <p>Deleted requirements:</p> <p>5.1d; Figure 5-1 (modified and moved as new Figure 6-1); 6.1e; 6.3.4b; 7.2.1c; 8.4.1a; 8.5a; 10.3.1e, k and l; 10.3.2b and c; 10.3.3b to e and h; 10.4.1a and b; 10.4.2.1a to g; 10.4.2.2 a to e; Table 10-1; 10.4.3.1a to c; 10.4.3.2 a to e; 10.4.3.3a to e; 10.4.3.4a to d; 10.4.3.5a to c; Figures 10-1 to 10-3 moved to clause 7.2.6; 10.5.1a to d; 10.5.2.1a to c; 10.5.2.2.1a to e; 10.5.2.2.2a to d.</p> <p>Added requirements:</p> <p>5.1f to h; Figure 6-1; 8.2.1b to d; 8.2.4e; 8.2.7a; 8.9a and b; 10.3.1n to p; 11.2.2.5a to c; 11.2.2.6a; 11.2.2.7a and b; 11.2.2.8a to c.</p> <p>Modified requirements:</p> <p>5.1a and b; 5.3.2b; 6.1a, b, d, f and g; 6.2.1b Note; 6.2.2a; 6.3.2b and f; 6.3.3b Note; 6.3.3c and h; 6.3.4a and e; 6.3.5.3.1a; 6.3.5.3.2a; Figure 6-4; Figure 6-5; 6.4.2a Note; 6.4.3b; 6.4.4b; 7.1e Note; 7.2.1b Note; 7.2.2b; 7.2.5e and f; 7.2.6b, d and e; Figure 7-1, 7-2 and 7-3 moved from clause 10; 7.2.8f and j; 8.2.1a; 8.2.2.2b Note; Figure 8-1; 8.2.3.1c; 8.2.4a to d; 8.2.5a and b; 8.2.6a; 8.3.1a; 8.3.2b; 8.3.2d Note; 8.3.2f and g; 8.4.1b and c Notes; 8.4.2.1b; 8.4.2.1d Note; 8.4.2.3a; 8.4.3.1a; 8.4.3.2a Note; 8.4.3.4a and b; 8.4.4.1c; 8.4.4.2g; 8.4.4.3b and c; 8.5.b Note; 8.5.d; 8.6.a; 8.7b, d and g; 8.8e to g; 8.8h Note; 9c; 10.3.1a, b, d, g to j and m; 10.3.2a, e and f; 10.3.3a f, g and i; 10.4.2.3a to d; 10.6.1a; 10.7.1a and b; 10.7.2.1.1b Note; 10.7.2.2a; 10.7.2.2b Note; 10.7.2.2c; 10.7.3a; 11.2.2.1a Note; 10.2.2.4a.</p> <p>Modified requirements where only a cross-reference was updated:</p> <p>6.3.2a; 6.3.3a; 7.2.6a; 8.4.4.2 Note; 8.6.b Note; 8.8h; 11.2.2.1b.</p> <p>Modified headings:</p> <p>6.3.4; 6.3.5.3; 8.2.4; 8.4.3.4; 10; 10.3; 10.3.2; 10.4; 10.4.2.</p>
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	<p>Editorial changes:</p> <ul style="list-style-type: none"><li>• Figure 10-1, Figure 10-2 and Figure 10-3 moved to clause 7 as Figures 7-1, Figure 7-2 and Figure 7-3</li><li>• Renumbering of Figures in clause 6 caused by addition of new Figure 6-1.</li><li>• Update of informative Figures: Figure 6-2, Figure 6-3.</li><li>• Correction of Reference [R3] and addition of [R8] in Annex B.</li></ul>
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# 1

## Scope

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This ECSS Engineering Standard specifies the fracture control requirements to be imposed on space segments of space systems and their related GSE.

The fracture control programme is applicable for space systems and related GSE where structural failure can result in a catastrophic hazard in accordance with the definition of ECSS-Q-ST-40 or alternative applicable document specified by the customer like those applicable to the ISS or Exploration systems or payloads.

The requirements contained in this Standard, when implemented, also satisfy the fracture control requirements applicable to the NASA and ISS hardware.

The NASA nomenclature differs in some cases from that used by ECSS. When ISS or Exploration-specific requirements and nomenclature are included, they are identified as such.

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

## 2

# Normative references

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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-32-02	Space engineering – Structural design and verification of pressurized hardware
ECSS-Q-ST-20	Space product assurance – Quality assurance
ECSS-Q-ST-40	Space product assurance – Safety
ECSS-Q-ST-70	Space product assurance – Materials, mechanical parts and processes
ECSS-Q-ST-70-15	Space product assurance - Non-destructive testing
ECSS-Q-ST-70-36	Space product assurance – Material selection for controlling stress-corrosion cracking
ECSS-Q-ST-70-45	Space product assurance – Mechanical testing of metallic materials
DOT/FAA/AR-MMPDS	Metallic Materials Properties Development and Standardization (MMPDS) (former MIL-HDBK-5)
EN ISO 6520-1	Welding and allied processes – Classification of geometric imperfections in metallic materials – Part 1: Fusion welding
ISO 17659	Welding – Multilingual terms for welded joints with illustrations

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**Terms, definitions and abbreviated terms**

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**3.1 Terms from other standards**

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

1. catastrophic
2. customer

NOTE In this standard, the customer is considered to represent the responsible fracture control or safety authority.

3. hazard

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

1. flaw

NOTE The term defect is used as synonymous.

2. maximum design pressure (MDP)
3. service life
4. proof test
5. limit load
6. structure
7. safe life

- c. For the purpose of this Standard, the following terms and definitions from ECSS-E-ST-32-02 apply:

1. burst pressure
2. hazardous fluid container
3. leak before burst, LBB
4. pressure component
5. pressure vessel
6. pressurized structure
7. sealed container
8. special pressurized equipment

9. visual damage threshold, VDT
    - NOTE 1 For typical implementation of thin-walled composite structure, the VDT is sometimes more specifically defined as the impact energy of an impactor with a hemi-spherical tip of 16 mm diameter resulting in 0,3 mm or more remaining surface deflection, after sufficiently long time to cover potential evolution of the indentation over time (due to e.g. wet ageing, fatigue loading, viscoelasticity of the resin) between impact and non-destructive testing.
    - NOTE 2 It can be time consuming to determine the VDT based on remaining surface deflection of 0,3 mm (see NOTE 1) after a sufficiently long time. Therefore, tests which cause mechanical damage corresponding to a deflection of at least 1 mm, immediately after impact, are sometimes used to determine the VDT.
  10. non-hazardous LBB failure mode
- d. For the purpose of this Standard, the following terms and definitions from ECSS-Q-ST-70-15 apply:
1. close visual testing
  2. special fracture control NDT
  3. standard fracture control NDT

## 3.2 Terms specific to the present standard

### 3.2.1 aggressive environment

combination of liquid or gaseous media and temperature that alters static or fatigue crack-growth characteristics from normal behaviour associated with an ambient temperature and laboratory air environment

### 3.2.2 analytical life

life evaluated analytically by crack-growth analysis or fatigue analysis

### 3.2.3 containment

damage tolerance design principle that, if a part fails, prevents the propagation of failure effects beyond the container boundaries

NOTE 1 A contained part is not considered PFCI, unless its release can cause a hazard inside the container. The container is a PFCI, and its structural integrity after impact is verified as part of fracture control activities.

NOTE 2 In this standard, the term containment in most cases also covers items which are e.g. restrained

by a tether to prevent the occurrence of hazardous events due to failure of the item.

### 3.2.4 crack-like defect

defect that has the same mechanical behaviour as a crack

NOTE 1 "Crack" and "crack-like defect" are considered synonymous in this standard.

NOTE 2 Crack-like defects can, for example, be initiated during material production, fabrication or testing or developed during the service life of a component.

NOTE 3 The term "crack-like defect" can include:

- For metallic materials flaws, inclusions, pores and other similar defects.
- For non-metallic materials, debonding, broken fibres, delamination, impact damage and other specific defects depending on the material.

### 3.2.5 crack aspect ratio, $a/c$

<part-through surface crack> ratio of crack depth to half crack length

### 3.2.6 crack aspect ratio, $a/c$

<part-through corner crack> ratio of crack depth to crack length

### 3.2.7 crack growth rate

rate of change of crack dimension with respect to the number of load cycles or time

NOTE For example  $da/dN$ ,  $dc/dN$ ,  $da/dt$  and  $dc/dt$ .

### 3.2.8 crack growth retardation

reduction of crack-growth rate due to overloading of the cracked structural member

### 3.2.9 critical crack size

the crack size at which the structure fails under the maximum specified load

NOTE The maximum specified load is in many cases the limit load, but sometimes higher than the limit load (e.g. for detected defects, composites and glass items)

### 3.2.10 critical initial defect, CID

critical (i.e., maximum) initial crack size for which the structure can survive the specified number of lifetimes.

### 3.2.11 critical stress-intensity factor

value of the stress-intensity factor at the tip of a crack at which unstable propagation of the crack occurs

NOTE 1 This value is also called the fracture toughness. The parameter  $K_{Ic}$  is the fracture toughness for plane strain and is an inherent property of the material. For stress conditions other than plane strain, the fracture toughness is denoted  $K_c$  or  $K_{Ie}$  for part through cracks. In fracture mechanics analyses, failure is assumed to be imminent when the applied stress-intensity factor is equal to or exceeds its critical value, i.e. the fracture toughness. See 3.2.22.

NOTE 2 The term fracture toughness is used as a synonymous.

### 3.2.12 cyclic loading

fluctuating load (or pressure) characterized by relative degrees of loading and unloading of a structure

NOTE For example, loads due to transient responses, vibro-acoustic excitation, flutter, pressure cycling and oscillating or reciprocating mechanical equipment.

### 3.2.13 damage tolerance threshold strain

<composite structural items> maximum strain level below which damage compatible with the sizes established by non-destructive testing (NDT), close visual testing, the damage threat assessment, or the minimum sizes imposed does not grow in  $10^6$  cycles ( $10^8$  cycles for rotating hardware) at a load ratio appropriate to the application

NOTE 1 Strain level is the maximum absolute value of strain in a load cycle.

NOTE 2 The damage tolerance threshold strain is a function of the material type and lay-up and is determined from test data in the design environment to the applicable or worst type and orientation of strain and flaw for a particular design and flaw size (e.g. the size determined by the VDT).

NOTE 3 For definition of "close visual testing" see ECSS-Q-ST-70-15.

### 3.2.14 damage tolerant

characteristic of a structure for which the amount of general degradation or the size and distribution of local defects expected during operation, or both, do not lead to structural degradation below specified performance

**3.2.15 defect**

see 'flaw' (3.1)

**3.2.16 detected defect**

defect known to exist in the hardware

**3.2.17 fail-safe**

<structures> damage-tolerance design principle, where a structure has redundancy to ensure that failure of one structural element does not cause general failure of the entire structure during the remaining lifetime

**3.2.18 fastener**

item that joins other structural items and transfers loads from one to the other across a joint

**3.2.19 fatigue**

cumulative irreversible damage incurred by cyclic application of loads to materials and structures

NOTE 1 Fatigue can initiate and extend cracks, which degrade the strength of materials and structures.

NOTE 2 Examples of factors influencing fatigue behaviour of the material are the environment, surface condition and part dimensions

**3.2.20 fracture critical item**

item classified as such

**3.2.21 fracture limited life item**

hardware item that requires periodic non-destructive re-testing or replacement to be in conformance with fracture control requirements

**3.2.22 fracture toughness**

materials' resistance to the unstable propagation of a crack

NOTE See critical stress intensity factor, 3.2.11.

**3.2.23 initial crack size**

maximum crack size, as defined by non-destructive testing, for performing a fracture control evaluation

**3.2.24 joint**

element that connects other structural elements and transfers loads from one to the other across a connection

**3.2.25 load enhancement factor, LEF**

factor to be applied on the load level of the spectrum of fatigue test(s) in order to demonstrate with the test(s) a specified level of reliability and confidence



NOTE 1 The LEF is dependent upon the material or construction, the number of test articles, and the duration of the tests.

NOTE 2 MIL-HDBK-17F, Volume 3, Section 7.6.3 gives an approach for calculating the LEF for composite structures.

### **3.2.26 loading event**

condition, phenomenon, environment or mission phase to which the structural system is exposed and which induces loads in the structure

### **3.2.27 load spectrum**

representation of the cumulative static and dynamic loadings anticipated for a structural element during its service life

NOTE Load spectrum is also called load history.

### **3.2.28 mechanical damage**

induced flaw in a composite hardware item that is caused by external influences, such as surface abrasions, cuts, or impacts

### **3.2.29 potential fracture critical item, PFCI**

item for which the initiation or propagation of cracks in structural items during the service life can result in a catastrophic hazard

NOTE 1 Pressure vessels and rotating machinery are always considered PFCI. See Figure 6-1.

NOTE 2 This can apply to other manned/human missions.

### **3.2.30 R-ratio**

ratio of the minimum stress to maximum stress

### **3.2.31 residual stress**

stress that remains in the structure, owing to processing, fabrication, assembly or prior loading

### **3.2.32 rotating machinery**

rotating mechanical assembly that has a kinetic energy of 19300 joules or more, or an angular momentum of 136 Nms or more

NOTE The amount of kinetic energy is based on  $0,5 I\omega^2$  where  $I$  is the moment of inertia ( $\text{kg.m}^2$ ) and  $\omega$  is the angular velocity ( $\text{rad/s}$ ).

### **3.2.33 stress-corrosion cracking, SCC**

initiation or propagation, or both, of cracks, owing to the combined action of applied sustained stresses, material properties and aggressive environmental effects

NOTE The maximum value of the stress-intensity factor for a given material at which no environmentally induced crack growth occurs

at sustained load for the specified environment  
is  $K_{ISCC}$ .

### 3.2.34 stress intensity factor, $K$

calculated quantity that is used in fracture mechanics analyses as a measure of the stress-field intensity near the tip of an idealised crack

NOTE Calculated for a specific crack size, applied stress level and part geometry. See 3.2.11.

### 3.2.35 structural screening

screening of structural elements with the objective to identify PFCI for the complete structure

NOTE The structure includes components or assemblies to sustain pressures, or to provide containment (see ECSS-E-ST-32).

### 3.2.36 threshold stress intensity range, $\Delta K_{th}$

stress-intensity range below which crack growth does not occur under cyclic loading

### 3.2.37 variable amplitude spectrum

load spectrum or history whose amplitude varies with time

## 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
a/c	crack aspect ratio (see 3.2.5)
AR	acceptance review
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
BS	British Standard
CDR	critical design review
CID	critical initial defect
COPV	composite overwrapped pressure vessel
DOT	United States Department of Transportation
DRD	document requirements definition
EDM	electrical discharge machining
EN	European Standard
EPFM	elastic-plastic fracture mechanics

<b>Abbreviation</b>	<b>Meaning</b>
<b>ESA</b>	European Space Agency
<b>FAD</b>	failure assessment diagram
<b>FCI</b>	fracture-critical item
<b>FCIL</b>	fracture-critical items list
<b>FE</b>	finite element
<b>FLLI</b>	fracture-limited life item
<b>FLLIL</b>	fracture-limited life items list
<b>FOD</b>	foreign object debris
<b>F<sub>ty</sub></b>	design tensile yield strength (in MPa)
<b>F<sub>tu</sub></b>	design tensile ultimate strength (in MPa)
<b>GSE</b>	ground support equipment
<b>ISO</b>	International Organisation for Standardisation
<b>ISS</b>	International Space Station
<b>J-R curve</b>	resistance curve based on J-integral
<b>K-R curve</b>	resistance curve based on stress intensity factor (K)
<b>LBB</b>	leak before burst
<b>LEF</b>	load enhancement factor
<b>LEFM</b>	linear elastic fracture mechanics
<b>K<sub>c</sub></b>	fracture toughness for stress conditions other than plane strain NOTE: See NOTE 1 of definition 3.2.11.
<b>K<sub>IC</sub></b>	plane strain fracture toughness
<b>K<sub>ISCC</sub></b>	threshold stress-intensity factor for stress-corrosion cracking
<b><math>\Delta K_{th}</math></b>	threshold stress-intensity range
<b>MDP</b>	maximum design pressure
<b>MEOP</b>	maximum expected operating pressure
<b>NASA</b>	National Aeronautics and Space Administration
<b>NDT</b>	non-destructive testing
<b>NHLBB</b>	non-hazardous leak before burst
<b>NSTS</b>	National Space Transportation System (NASA Space Shuttle)
<b>PDR</b>	preliminary design review
<b>PFCI</b>	potential fracture-critical item
<b>PFCIL</b>	potential fracture-critical items list
<b>R</b>	ratio of the minimum stress to maximum stress
<b>RFCP</b>	reduced fracture-control programme
<b>SAE</b>	Society of Automotive Engineers

<b>Abbreviation</b>	<b>Meaning</b>
SCC	stress-corrosion cracking
SI	international system of units
SRR	system requirements review
US	ultrasonic
UTS	ultimate tensile strength
VDT	visual damage threshold

### 3.4 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.

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# 4 Principles

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The following assumptions and prerequisites are the basis of the implementation of the requirements contained in this standard. They can be used as reference for example when alternative approaches, not directly covered by the requirements of this standard, are assessed for equivalent safety or reliability.

- All structural elements contain crack-like defects located in the most critical area of the component in the most unfavourable orientation. The inability of non-destructive testing (NDT) techniques to detect such defects does not negate this assumption, but merely establishes an upper bound on the initial size of the cracks which result from these defects. For conservatism, this crack size then becomes the smallest allowable size to be used in any analysis or assessment.
- After undergoing a sufficient number of cycles at sufficiently high stress amplitude, materials exhibit a tendency to propagate cracks, even in non-aggressive environments.
- Whether, under cyclic or sustained tensile stress, a pre-existing (or load-induced) crack does or does not propagate depends on:
  - the material behaviour with crack;
  - the initial size and geometry of the crack;
  - the presence of an aggressive environment;
  - the geometry of the item;
  - the magnitude and number of loading cycles;
  - the duration of sustained load;
  - the temperature of the material.
- For metallic materials, the engineering discipline of linear elastic fracture mechanics (LEFM) provides analytical tools for the prediction of crack propagation and critical crack size. Validity of LEFM, depends on stress level, crack configuration and structural geometry. The engineering discipline of elastic-plastic fracture mechanics (EPFM) provides analytical tools for the prediction of crack initiation, stable ductile crack growth and critical crack size.
- For non-metallic materials (other than glass and other brittle materials) and fibre-reinforced composites (both with metal and with polymer matrix), linear elastic fracture mechanics technology is agreed by most

authorities to be inadequate, with the exception of interlaminar fracture mechanics applied to debonding and delamination. Fracture control of these materials relies on the techniques of safe life assessment supported by tests, containment, fail safe assessment, and proof testing.

Composite, bonded and sandwich items are manufactured and verified to high quality control standards to assure aerospace quality hardware. The hardware developer of composite, bonded and sandwich items uses only manufacturing processes and controls (NDT, coupon tests, sampling techniques, etc.) that are demonstrated to be reliable and consistent with established aerospace industry practices for composite/bonded structures.

- The observed scatter in measured material properties and fracture mechanics analysis uncertainties is considered.

NOTE For example, scatter factor and LEF

- For ISS payloads and systems, entities controlling the pressure are two-fault tolerant.

NOTE For example, regulators, relief devices and thermal control systems

**5****Fracture control programme**

---

**5.1 General****ECSS-E-ST-32-01\_0810001**

- a. A fracture control programme shall be implemented by the supplier for space systems and their related GSE in conformance with this Standard, where structural failure can result in a catastrophic hazard in accordance with the definition of ECSS-Q-ST-40 or alternative applicable document specified by the customer.

NOTE Example of requirements superseding the ones of ECSS-Q-ST-40: human spaceflight requirements like those applicable to the ISS or Exploration systems or payloads.

**ECSS-E-ST-32-01\_0810002**

- b. Fracture control requirements shall be applied for PFCIs identified in accordance with requirements from clause 6.1.

**ECSS-E-ST-32-01\_0810317**

- c. Implementation of fracture control for structural GSE may be limited to items which are not covered by other structural safety requirements.

NOTE In many cases this limits fracture control verification to elements directly interfacing with flight hardware.

**ECSS-E-ST-32-01\_0810004**

- d. <<deleted>>

**ECSS-E-ST-32-01\_0810318**

- e. For unmanned, single-mission, space vehicles and their payloads, and GSE the reduced fracture control programme, specified in clause 11, may be implemented.

**ECSS-E-ST-32-01\_0810334**

- f. In case a project is rated highly critical by the customer due to other aspects than the catastrophic hazard as defined in ECSS-Q-ST-40, the applicability of this standard may be extended to mission critical elements.

NOTE For each project, it is good practice that the developer agrees with the customer the extent of applicability of the standard to loss of system and/or loss of mission hazards. It is recommended that this agreement is achieved as early as possible, preferably in the SOW and then reflected in the Fracture Control Plan.

**ECSS-E-ST-32-01\_0810335**

- g. Due to the potential significant technical and programmatic impacts, an extension of applicability of Fracture Control specified in 5.1f shall be implemented with the baseline requirements specification and precise identification of the elements that are subject of extension.

**ECSS-E-ST-32-01\_0810336**

- h. Extension of applicability of Fracture Control specified in 5.1f should be defined prior to Phase B "Preliminary definition" as per ECSS-M-ST-10, or equivalent project phase.

## 5.2 Fracture control plan

**ECSS-E-ST-32-01\_0810006**

- a. The supplier shall prepare and implement a fracture control plan in conformance with ECSS-E-ST-32 'Fracture control plan – DRD'.

**ECSS-E-ST-32-01\_0810007**

- b. The fracture control plan shall be subject to approval by the customer.

**Figure 5-1: <<deleted, modified and moved to clause 6 as new Figure 6-1>**



## 5.3 Reviews

### 5.3.1 General

**ECSS-E-ST-32-01\_0810008**

- a. Fracture control activities and status shall be reported during all project reviews.

NOTE For project reviews, see ECSS-M-ST-10.

### 5.3.2 Safety and project reviews

**ECSS-E-ST-32-01\_0810009**

- a. The schedule of fracture control activities shall be related to, and support, the project safety review schedule.

NOTE As specified in ECSS-Q-ST-40, safety reviews are performed in parallel with major project reviews.

**ECSS-E-ST-32-01\_0810010**

- b. Fracture control documentation shall be provided for the reviews as follows:

1. For a system requirements review (SRR)  
The results of preliminary hazard analysis and fracture control screening (which follows the methodology given in Figure 6-1) and a written statement as to whether or not fracture control is applicable.
2. For a preliminary design review (PDR)
  - (a) A written statement which either confirms that fracture control is required or else provides a justification for not implementing fracture control.
  - (b) Identification of fracture control-related project activities in the fracture control plan including:
    - (1) Definition of the scope of planned fracture control activities dependent upon the results of the hazard-analysis and fracture control screening performed.
    - (2) Identification of low-risk fracture items.
    - (3) Identification of primary design requirements and constraints which are affected by or affecting fracture control implementation.
  - (c) Submission of the fracture control plan to the customer for approval.
  - (d) Lists of potential fracture critical items and fracture critical items in conformance with clause 6.4.2.

3. For a critical design review (CDR)
  - (a) A final fracture control plan which is approved by the customer.
  - (b) Verification requirements for non-destructive testing procedures and personnel.
  - (c) The status of fracture control activities, together with a specific schedule for completion of the verification activities.
  - (d) A description and summary of the results of pertinent analyses and tests.
  - (e) List of potential fracture critical items in conformance with clause 6.4.2.
  - (f) List of fracture critical items in conformance with clause 6.4.2.
  - (g) List of fracture limited-life items in conformance with clause 6.4.2.
4. For an acceptance review (AR) or qualification review (QR)
  - (a) A fracture control summary report in conformance with clause 6.4.4, showing completion of all fracture control verification activities.
  - (b) Relevant test, non-destructive testing, procurement and analysis reports in conformance with clause 6.4.
  - (c) List of potential fracture critical items in conformance with clause 6.4.2.
  - (d) List of fracture critical items in conformance with clause 6.4.2.
  - (e) List of fracture limited-life items in conformance with clause 6.4.2.
  - (f) Pressure-vessel summary log in conformance with applicable safety requirements.

NOTE 1 to item 5.3.2b.2(b): For the fracture control plan, see 5.2.

NOTE 2 to item 5.3.2b.3(d): See clause 6.4.

## 6

# Identification and evaluation of PFCI

## 6.1 Identification of PFCIs

### ECSS-E-ST-32-01\_0810011

- a. Structural items for which implementation of fracture control programme is performed shall be selected in conformance with Figure 6-1, classified as PFCI, and identified by structural screening for the complete structure, including related GSE directly connected to the flight structure.

NOTE This includes structural items whose failure can result in a catastrophic hazard.

### ECSS-E-ST-32-01\_0810319

- b. For unmanned, single-mission, space vehicles and their payloads, and GSE the identification of PFCIs may be limited to the items listed in clause 11.2.2.1.

### ECSS-E-ST-32-01\_0810013

- c. For the purpose of 6.1g, the structural screening to identify PFCI shall be documented.

NOTE The screening results, incl. explanation why certain structural items (if any) are not considered as PFCI, can be reported e.g. in the PFCIL

### ECSS-E-ST-32-01\_0810014

- d. In support of the structural screening, the hazard analysis of the space system, performed in conformance with ECSS-Q-ST-40 clause on "Hazard analysis", shall identify where structural failure of flight hardware or GSE items can result in catastrophic hazards.

NOTE 1 The outcome of safety reviews can provide input to the selection of specific hazards to be controlled by fracture control implementation.

NOTE 2 For human spaceflight missions, the following are examples of situations which have the potential to cause a catastrophic hazard:

1. Where failure of the item can result in the release of any element or fragment with a mass above a limit during launch or landing, as agreed in the safety review. For the Space Shuttle the mass limit was 113,5 g (0,25 pounds). For other launch vehicles, a different limit can apply.

2. Where failure of the item can result in the release or separation of any tension preloaded structural element or fragment with a mass above a limit during launch or landing, as agreed in the safety review. For the ISS the mass limit is 13 g (0,03 pounds) if the item has a fracture toughness ( $K_{Ic}$ ) to tensile yield strength ratio less than  $1,66 \text{ mm}^{1/2}$  ( $0,33 \text{ in}^{1/2}$ ), or if the item is a steel bolt whose ultimate strength exceeds 1 240 MPa (180 ksi). For other human spaceflight programmes, a different limit can apply.

3. Where failure of a sealing barrier item can result in the release of hazardous substances, or a hazardous amount of fluid.

4. Where failure of the item can prevent configuration for safe descent from orbit.

5. Where failure of the item can result in the release during zero gravity flight of any mass that can impact critical hardware or crew personnel, with a velocity or momentum above a limit, as agreed in the safety review. For the ISS the velocity limit is 10,7 m/s (35 ft/s), and the momentum limit is 1,21 Ns (8,75 ft-lb/s), for items released inside a habitable module. For other human spaceflight programmes, as well as outside ISS habitable modules, a different limit can apply.

NOTE 3 This requirement can also apply to other manned/human missions.

**ECSS-E-ST-32-01\_0810015**

e. <<deleted>>

**ECSS-E-ST-32-01\_0810016**

f. Containers and restraining elements, which prevent failed items from creating a catastrophic hazard, shall be classified PFCI.

NOTE In addition to verification as safe-life or fail-safe or low risk item (as appropriate), containers and restraining elements are verified to provide

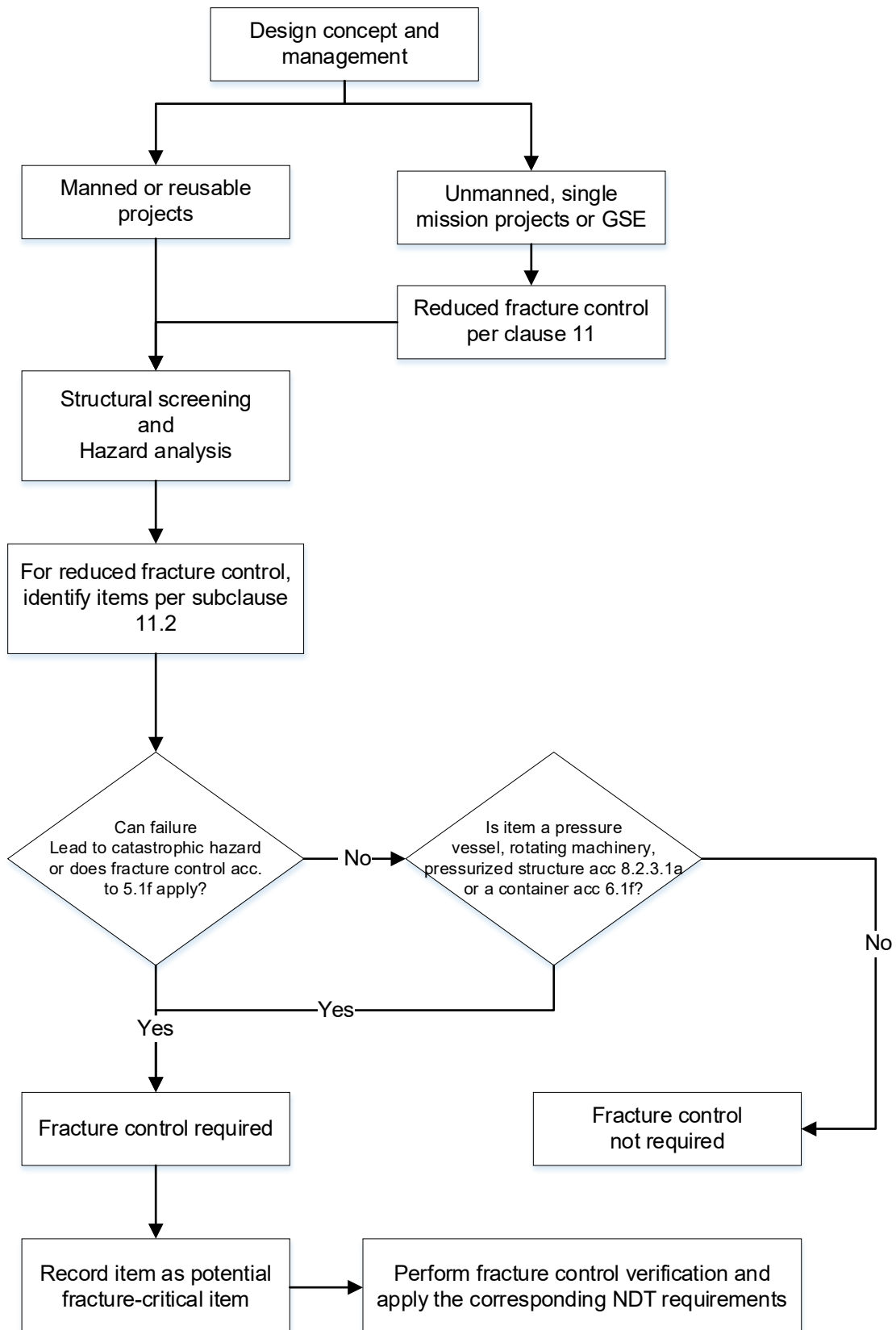
adequate containment or restraint in case of failure of the items.

**ECSS-E-ST-32-01\_0810017**

- g. Potential fracture-critical items (PFCI) shall be included in the potential fracture-critical item list (PFCIL), specified in clause 6.4.

**ECSS-E-ST-32-01\_0810018**

- h. In order to ensure that the implementation of the fracture control programme is compatible with the current design and service-life scenario, hazard analysis and structural screening shall be repeated to incorporate design progress and design changes.



ECSS-E-ST-32-01\_0810306

**Figure 6-1: Identification of PFCI**

## 6.2 Evaluation of PFCIs

### 6.2.1 Damage tolerance

**ECSS-E-ST-32-01\_0810019**

- a. Each PFCI shall be damage tolerant.

**ECSS-E-ST-32-01\_0810020**

- b. For the damage tolerance evaluation of PFCI, one of the following design principles shall be used in conformance with 6.3:
1. Safe life, or
  2. Fail-safe, or
  3. Low-risk fracture

NOTE 1 An overview of the fracture control evaluation procedure, including damage tolerance design approaches, classification of Potential Fracture Critical Items and the relevant documentation is illustrated in Figure 6-2.

NOTE 2 Another way to implement damage tolerance is containment. Containment verification is considered a fracture control activity (see clause 6.3.4). The container (or restraint) is a PFCI (see 6.1f). Contained (or restrained) items are however not considered PFCI (see Figure 6-1).

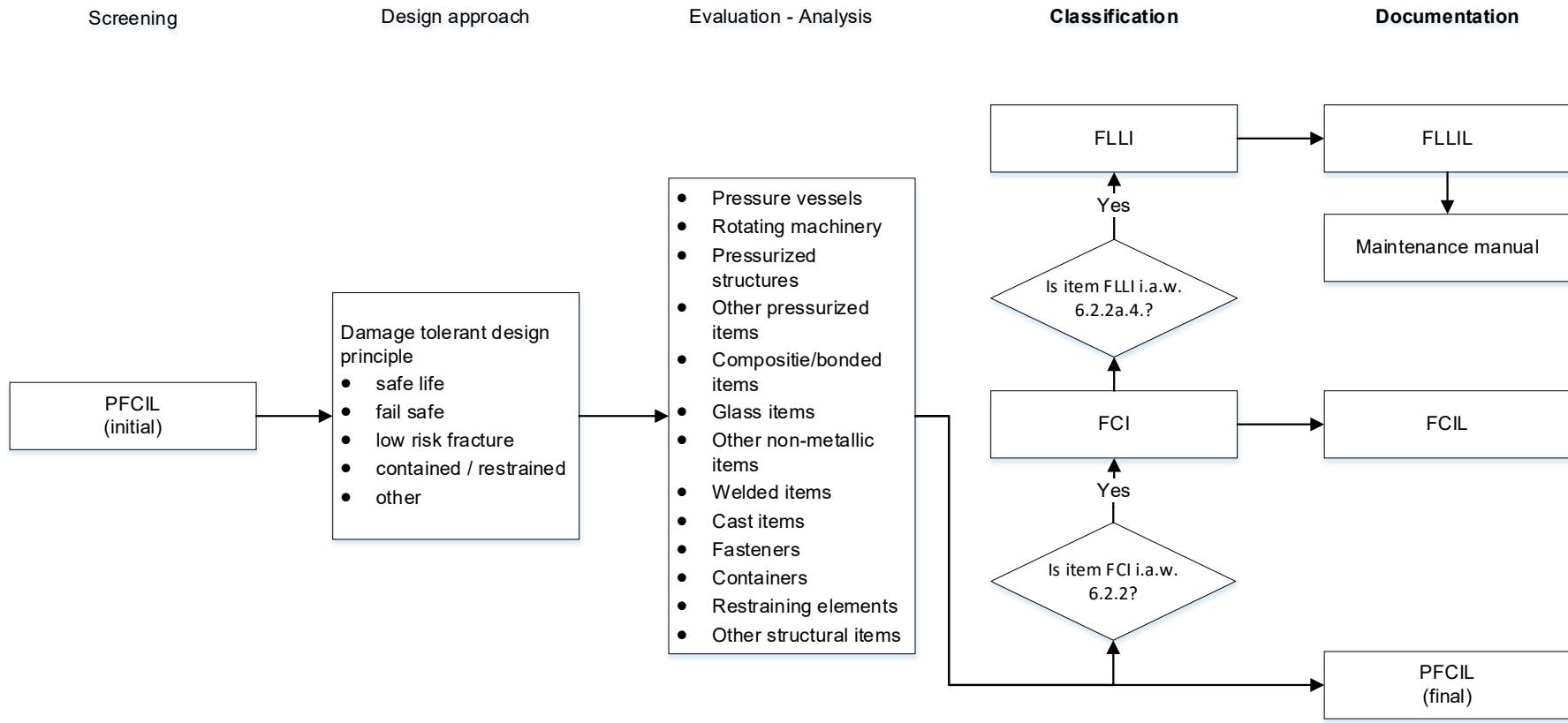


Figure 6-2: Fracture control evaluation procedures



## 6.2.2 Fracture critical item classification

ECSS-E-ST-32-01\_0810021

- a. The following items shall be classified as fracture critical item (FCI):
1. Composite, bonded, sandwich or other non-metallic PFCI, unless fail safe, low-risk fracture or contained.
  2. Metallic PFCI which require NDT better than standard fracture control NDT, as specified in clause 10.3 and ECSS-Q-ST-70-15.
  3. Pressure vessels, manned pressurized structures, or other pressurized structures specified fracture critical in clause 8.2.3.
  4. PFCI which require periodic non-destructive re-testing or replacement in order to achieve the required life.
  5. Rotating machinery as specified in 3.2.32.

NOTE 1 to item 2: For standard and special fracture control NDT, see in particular clause 9 of ECSS-Q-ST-70-15.

NOTE 2 to item 2: This means that the set of metallic FCI is reduced w.r.t. the practice defined in standards applied by for example NASA in human spaceflight programs (example: NASA-STD-5019 'fracture control requirements for spaceflight hardware'), which considers also metallic items verified with standard fracture control NDT as FCI (as well as pressurized hardware verified i.a.w. 8.2.4 "Pressure components, including lines and fittings" and 8.2.6 "Hazardous fluid containers"). Therefore, additional requirements apply not only to FCI, but also to all PFCI verified as safe life, see for example: clause 10.2 "Nonconformances" and 10.6 "Traceability".

NOTE 3 to item 4: Such items are called fracture limited-life items (FLLI) as a subset of FCI.

NOTE 4 to item 4: Having FLLI is not always desirable from programmatic considerations.

## 6.3 Compliance procedures

### 6.3.1 General

**ECSS-E-ST-32-01\_0810022**

- a. The verification of PFCIs shall be done by analysis or by test or both.

NOTE For various items special compliance procedure requirements are specified in clause 8.

**ECSS-E-ST-32-01\_0810023**

- b. The methodology applied for evaluation by test shall be subject to customer approval.

NOTE Customer approval is specified, because evaluation by test is not specified to the same level of detail than evaluation by analysis. Evaluation by test is similar to evaluation by analysis, where appropriate and not specified otherwise.

### 6.3.2 Safe life items

**ECSS-E-ST-32-01\_0810024**

- a. The evaluation procedure for a PFCI considered as a safe life item shall be in conformance with Figure 6-4, for metallic items, and Figure 6-5, for composite, bonded and sandwich items.

**ECSS-E-ST-32-01\_0810025**

- b. Except where it is explicitly specified otherwise, the initial crack or damage size used for the verification (by analysis or test) of safe life items shall be detectable by the applied NDT with at least 90% probability and 95% confidence.

**ECSS-E-ST-32-01\_0810026**

- c. For metallic materials, the worst crack-like defect in the part shall not grow to such an extent that the minimum specified performance is no longer assured within a specified safe life interval, using a design life factor of at least four (4).

NOTE For example, minimum specified performance can be the limit-load capability (no failure or burst or excessive deformation) or no-leak, depending on the hazard to be prevented.

**ECSS-E-ST-32-01\_0810027**

- d. For metallic materials the maximum sustained stress-intensity factor  $K_{max}$ , shall not exceed the threshold stress-intensity factor for stress-corrosion cracking  $K_{ISCC}$ .

**ECSS-E-ST-32-01\_0810028**

- e. For composite, bonded and sandwich items, the worst damage in the part shall not grow within a safe life interval, using a design life factor of 1 and a load enhancement factor of 1,15, after which the structure is still able to assure ultimate load capability.

**ECSS-E-ST-32-01\_0810029**

- f. For limited life items, a reduced service life shall be verified, which allows non-destructive re-testing or replacement of the items when the analytical life is less than one flight.

**ECSS-E-ST-32-01\_0810030**

- g. For metallic materials, safe life analysis shall be performed as specified in clause 7.

**ECSS-E-ST-32-01\_0810031**

- h. Safe life items made of non-metallic materials, other than composite, bonded and sandwich items, shall be in conformance with 8.5 and 8.7.

### 6.3.3 Fail-safe items

**ECSS-E-ST-32-01\_0810032**

- a. The evaluation procedure for a PFCI considered as fail-safe item shall be as specified in Figure 6-5.

**ECSS-E-ST-32-01\_0810033**

- b. The structure remaining after failure of any element of the PFCI shall sustain the limit loads with a safety factor of 1,0 for metallic and glass items or 1,15 for composite, bonded and sandwich items, without losing minimum specified performance.

NOTE 1 Minimum specified performance includes prevention of large scale yielding.

NOTE 2 For cases subjected to the reduced fracture control programme of clause 11 and where fatigue is not significant it is acceptable, subject to customer approval, to replace the load enhancement factor 1,15 by a lower factor equal to or higher than 1,0.

**ECSS-E-ST-32-01\_0810034**

- c. The failure of the item shall not result in the release of any part or fragment which can create a catastrophic hazard.

NOTE For payloads on the ISS, including transportation events to ISS, as minimum the mass and momentum limits defined in 6.1e are used. More in general, the maximum acceptable mass and velocity of released items is based on the results of the hazard analysis.

**ECSS-E-ST-32-01\_0810035**

- d. For metallic parts the fatigue life of the remaining structure shall be evaluated by linear damage accumulation rule (Miner's rule).

**ECSS-E-ST-32-01\_0810036**

- e. For metallic parts, mean fatigue life material characteristics and a design life factor of at least four (4) shall be used.

**ECSS-E-ST-32-01\_0810037**

- f. For composite, bonded and sandwich parts the fatigue assessment shall be performed using the mean fatigue life material characteristics, a design life factor of 1 and a load enhancement factor of 1,15.

**ECSS-E-ST-32-01\_0810320**

- g. In the case that no fatigue data are available, the fatigue analysis for metallic parts may be replaced by a crack growth analysis using an equivalent initial crack size of  $a = c = 0,125$  mm (corner or surface crack), and demonstrating no failure after four (4) times the service life.

**ECSS-E-ST-32-01\_0810039**

- h. For limited life items, a reduced service life shall be verified, which allows replacement of the items when less than one flight life remains.

**ECSS-E-ST-32-01\_0810040**

- i. Fail-safe items made of non-metallic materials, other than composite, bonded, sandwich and glass items, shall be in conformance with 8.5.

### 6.3.4 Contained and restrained items

**ECSS-E-ST-32-01\_0810041**

- a. It shall be verified by analysis or test that the release of any loose item which can create a catastrophic hazard is effectively prevented by an enclosure, protective cover or restraining element.

NOTE Successful containment verification implies not to consider the contained items as PFCI. The

containing or restraining elements are PFCI (see 6.1).

**ECSS-E-ST-32-01\_0810042**

- b. <<deleted>>

**ECSS-E-ST-32-01\_0810043**

- c. For metallic enclosures, it shall be verified that the loose item does not penetrate or fracture the enclosure with a safety factor of 1,5 on its kinetic energy.

**ECSS-E-ST-32-01\_0810044**

- d. For composite, bonded and sandwich enclosures, it shall be verified by test (or analysis supported by test) that the loose part does not penetrate or fracture the enclosure with a safety factor of 1,5 on its kinetic energy.

**ECSS-E-ST-32-01\_0810045**

- e. Composite, bonded and sandwich enclosures shall not be fracture critical in conformance with clause 6.2.2, for reasons such as providing a single point of failure support that can create a catastrophic hazard if the enclosure failed.

**ECSS-E-ST-32-01\_0810321**

- f. Engineering judgment supported by documented technical rationale may be used when it is obvious that an enclosure, a barrier, or a restraint prevents the part from escaping.

NOTE Examples of such enclosures that have obvious containment capability include metallic boxes containing closely packed electronics, detectors, cameras, and electric motors; pumps and gearboxes having conventional housings; and shrouded or enclosed fans not exceeding 200 mm in diameter and an 8 000 revolutions per minute (rpm) speed.

**ECSS-E-ST-32-01\_0810047**

- g. When enclosures are designed to be opened the closure devices shall be single failure tolerant against failure to close if they are required to be closed again to establish containment for a later phase of the mission.

## **6.3.5 Low-risk fracture items**

### **6.3.5.1 General**

**ECSS-E-ST-32-01\_0810309**

- a. Metallic low-risk fracture items shall be in conformance with 6.3.5.2 and 6.3.5.3.

**ECSS-E-ST-32-01\_0810310**

- b. Composite, bonded and sandwich low-risk fracture items shall be in conformance with 8.4.4.3.

### **6.3.5.2 Limitations on applicability for metallic parts**

**ECSS-E-ST-32-01\_0810048**

- a. The following PFCI shall not be accepted as low risk fracture items:
1. Pressure shells of human-tended modules or personnel compartments.
  2. Pressure vessels.
  3. Pressurized components in a pressurized system containing a hazardous fluid.
  4. High-energy or high momentum rotating machinery.
  5. Fasteners.

**ECSS-E-ST-32-01\_0810049**

- b. The maximum tensile stress based on net cross-sectional area in the part at limit load shall be no greater than 30 percent of the ultimate tensile strength for the metal used.

**ECSS-E-ST-32-01\_0810050**

- c. The use of low-risk fracture classification shall be agreed with the customer.

### **6.3.5.3 Inherent assurance against catastrophic failure from a flaw for metallic parts**

#### **6.3.5.3.1 Remote possibility of significant crack-like defect**

**ECSS-E-ST-32-01\_0810051**

- a. The following criteria shall be met:
1. Low-risk fracture items are fabricated from a well-characterized metal, procured in conformance with an aerospace standard or equivalent standard approved by the customer, which is selected from Table 5-1 (Alloys with high resistance to stress-corrosion

cracking) of ECSS-Q-ST-70-36 and therefore not sensitive to stress corrosion cracking in environmental conditions addressed by ECSS-Q-ST-70-36.

2. Low-risk fracture items are not fabricated using a process that has a recognized risk of causing significant crack-like defects, such as welding, forging, casting, or quenching heat treatment (for materials susceptible to cracking during heat treatment quenching) unless specific NDT or other testing, which has been approved by the customer, is applied to sufficiently screen for defects.
3. Low-risk fracture items receive visual testing of 100% of the surface of the finished part.
4. Low-risk fracture items are non-destructive tested at the individual part level
5. <<deleted>>

NOTE 1 to item 2: It can be assumed that significant crack-like defects do not occur during machining of sheet, bar, and plate products from materials that are known to have good machinability properties, do not have low fracture toughness (i.e. when the ratio  $K_{Ic}/F_{ty} < 1,66 \sqrt{\text{mm}}$ ; for steel bolts with unknown  $K_{Ic}$ , low fracture toughness is assumed when  $F_{tu} > 1240 \text{ MPa}$ ), and are metals or alloys produced in conformance with aerospace specifications and standards or equivalent grade specifications.

NOTE 2 to item 2: Low-risk fracture items meet NDT standards consistent with aerospace practices to ensure aerospace-quality flight hardware. This includes raw material NDT.

NOTE 3 to item 3: See ECSS-Q-ST-70-15 for guidance, in particular clause 6.1 "Visual testing".

NOTE 4 to item 4: This is to assure maximum accessibility.

#### 6.3.5.3.2 Remote possibility of significant crack growth

##### ECSS-E-ST-32-01\_0810052

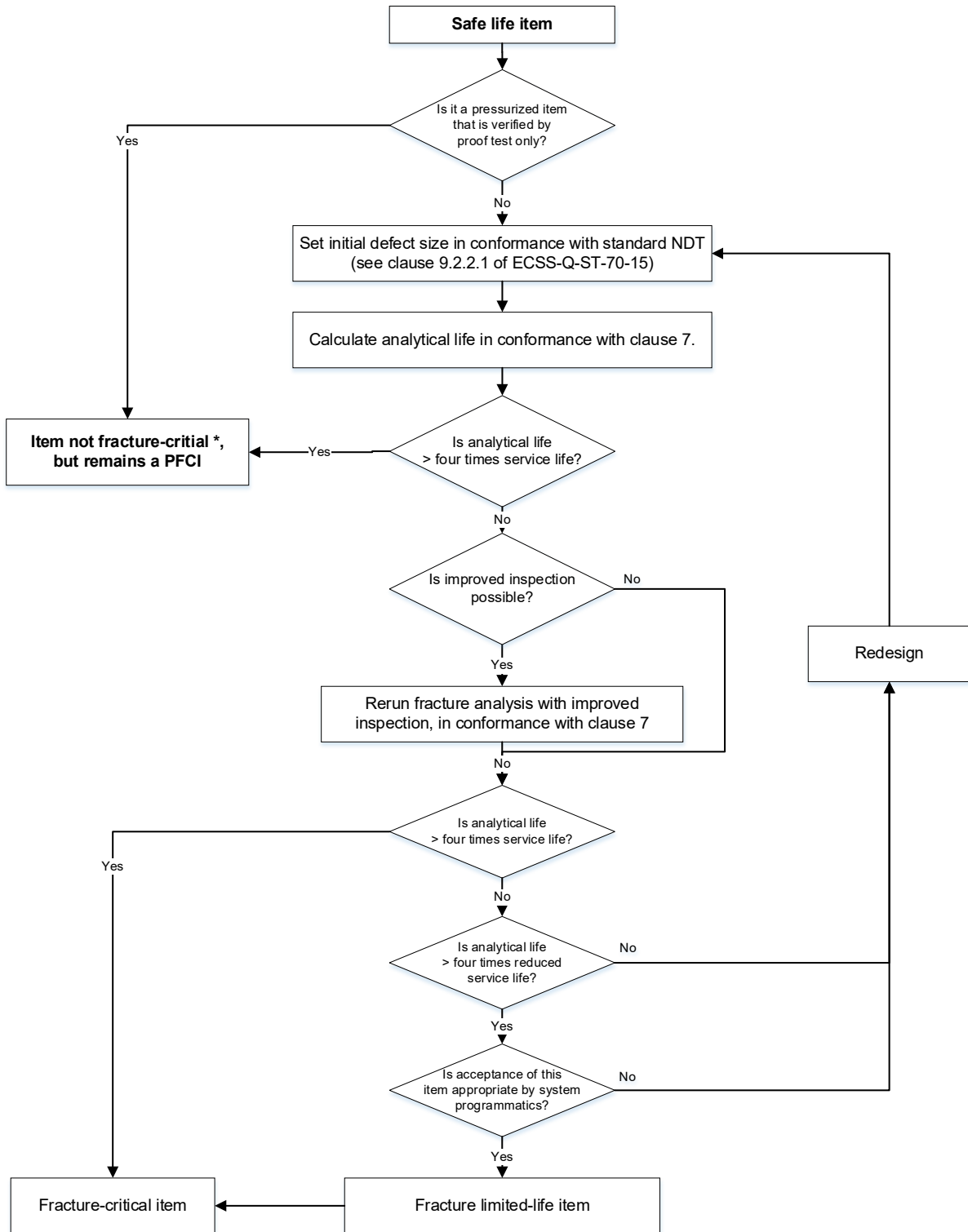
- a. One of the following criteria shall be met:
  1. Low-risk fracture items are not subjected to fatigue loading beyond acceptance or normal protoflight testing (if any), transportation, and one mission (including a potential aborted mission), or
  2. Low-risk fracture items are shown to possess acceptable resistance to crack growth from potential initial defects caused by machining, assembly, and handling, by demonstrating that the following

assumed initial cracks do not grow to failure in less than four complete service lifetimes.

- (a) For items of more than 3mm thickness or diameter, surface cracks of  $a=3$  mm depth and  $2c=6$  mm length and corner cracks of  $a=c=3$  mm radius from holes and edges,
- (b) For items of less than 3 mm thickness or diameter, through cracks of  $2c=6$  mm length and edge cracks from holes and edges of  $c=3$  mm length.

NOTE For the definition of the dimensions  $a$  and  $c$  see Figure 7-1, Figure 7-2 and Figure 7-3.



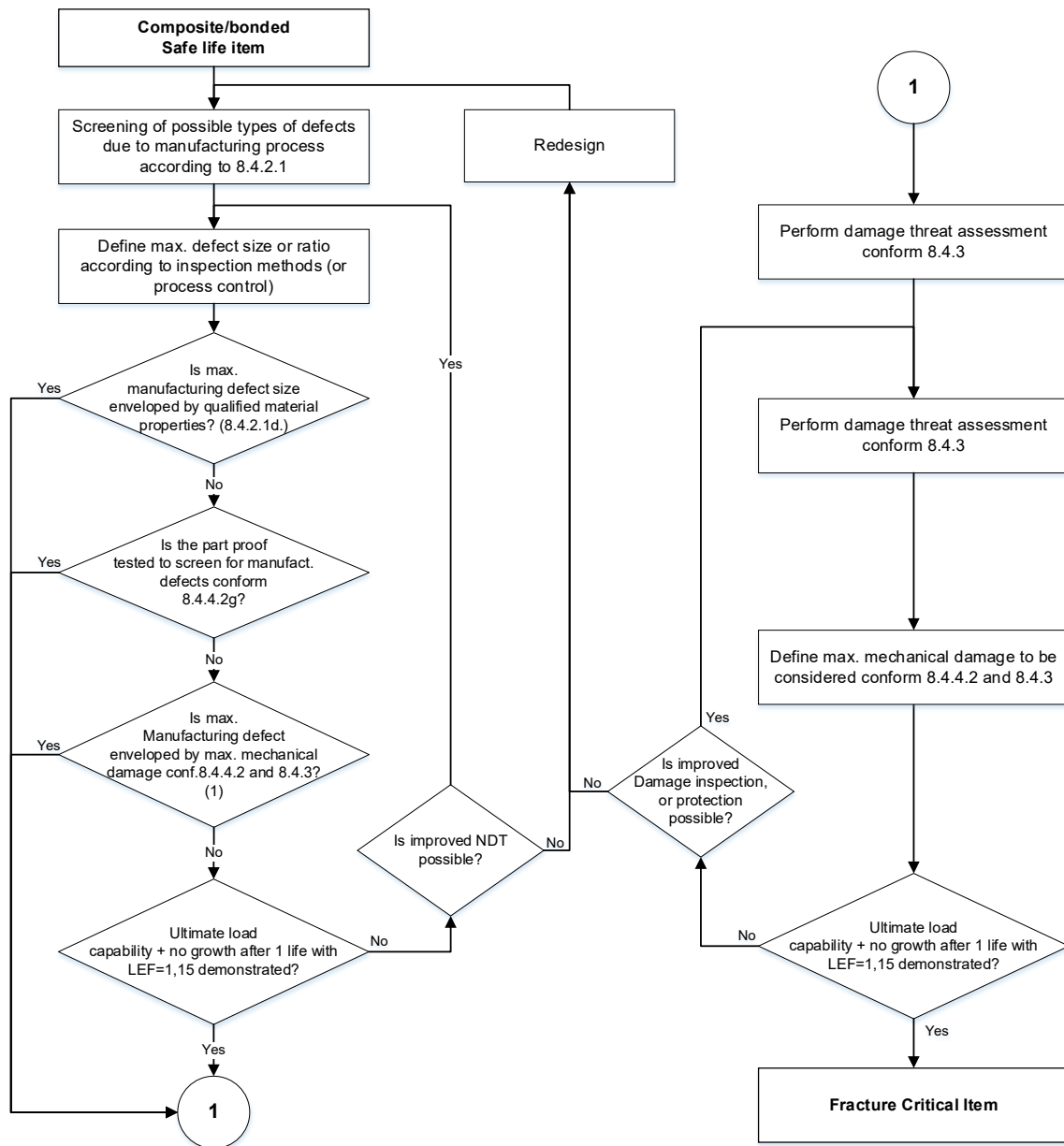


Note: Including metal matrix composites reinforced by particles or whiskers.

**Legend**

\* unless fracture critical for another reason (see 6.2.2)  
> greater than

**Figure 6-3: Safe life item evaluation procedure for metallic materials**

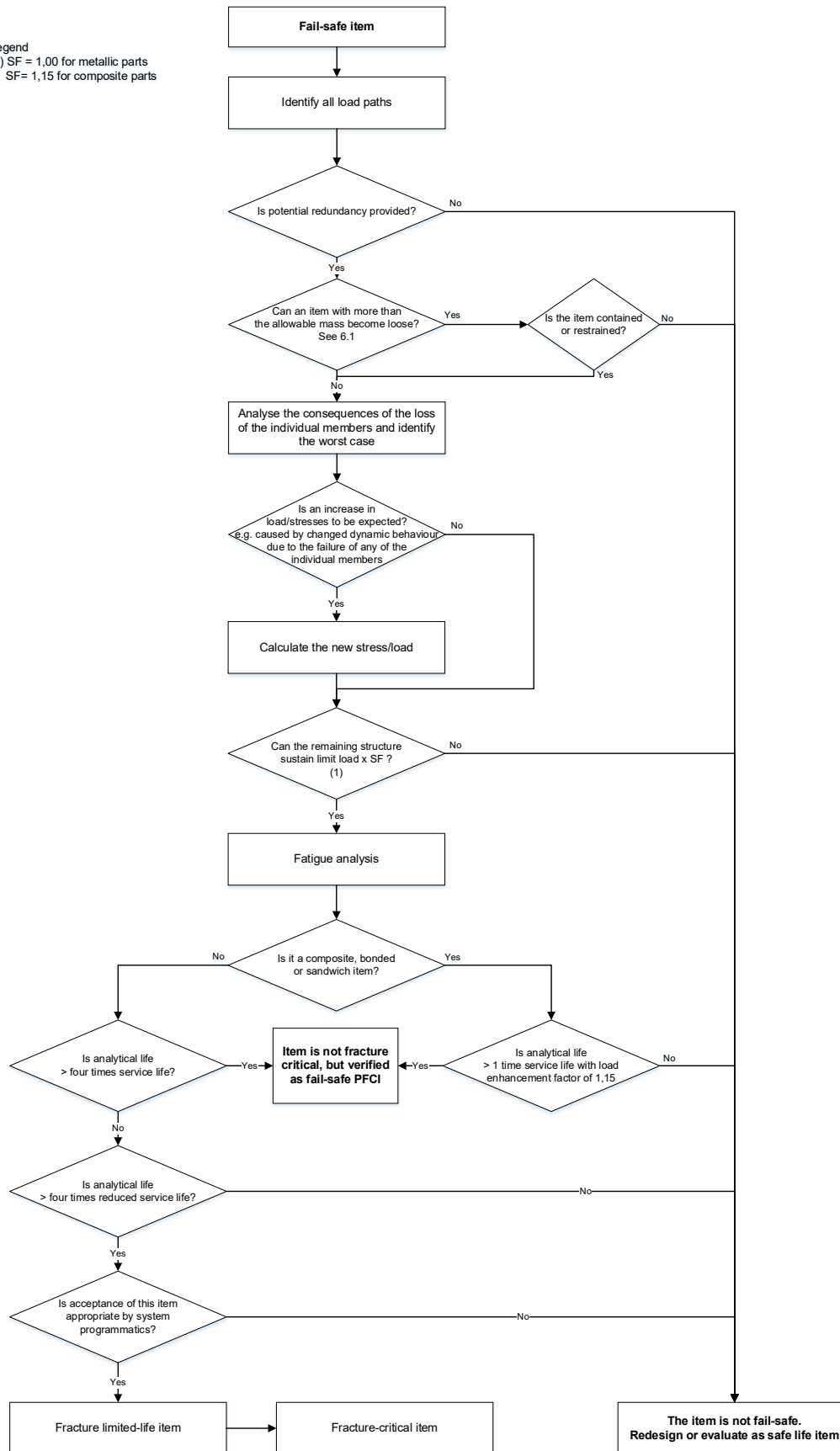


(1) only in the case where the manufacturing defect type is comparable to the mechanical damage considered at 8.4.4.2 and 8.4.3 (i.e. delamination and impact damage, but not e.g. porosity)

ECSS-E-ST-32-01\_0810307

**Figure 6-4: Safe life item evaluation procedure for composite, bonded and sandwich items**

Legend  
(1) SF = 1,00 for metallic parts  
SF= 1,15 for composite parts



ECSS-E-ST-32-01\_0810308

Figure 6-5: Evaluation procedure for fail-safe items

## 6.4 Documentation requirements

### 6.4.1 Fracture control plan

ECSS-E-ST-32-01\_0810053

- a. A fracture control plan shall be provided in conformance with clause 5.2.

### 6.4.2 Lists

ECSS-E-ST-32-01\_0810054

- a. A PFCIL, FCIL and FLLIL shall be provided in conformance with ECSS-E-ST-32 'Fracture control items lists (PFCIL, FCIL and FLLIL) - DRD'

NOTE 1 The potential fracture-critical item list (PFCIL) is compiled from the results of the fracture control screening.

NOTE 2 The fracture-critical item list (FCIL) includes the same information as the PFCIL for each FCI, and in addition specifies a reference to the document which shows for each item the fracture analysis and/or test results and the analytical life.

NOTE 3 The fracture limited-life item list (FLLIL) includes the same information as the FCIL for each FLLI, and in addition specify the NDT method and period, and identifies the maintenance manual in which NDT procedures are defined.

NOTE 4 The above three lists can be reported in one document.

### 6.4.3 Analysis and test documents

ECSS-E-ST-32-01\_0810055

- a. The analysis of all PFCIs, FCIs, contained and restrained items shall be documented in a fracture control analysis report in conformance with ECSS-E-ST-32 'Fracture control analysis (FCA) - DRD'.

ECSS-E-ST-32-01\_0810056

- b. When testing is used in addition to analysis of PFCIs, FCIs, contained and restrained items, the test method and test results shall be documented in test plans, specifications, procedures and reports in conformance with:

1. ECSS-E-ST-10-03 'Assembly, integration and test plan (AITP) - DRD',

2. ECSS-E-ST-10-03 'Test specification (TSPE) - DRD',
3. ECSS-E-ST-10-03 'Test procedure (TPRO) - DRD',
4. ECSS-E-ST-10-02 'Test report (TRPT) - DRD'.

NOTE The "AITP" can be limited to a "Test plan".

#### 6.4.4 Fracture control summary report

**ECSS-E-ST-32-01\_0810057**

- a. A fracture control summary report shall be provided with each deliverable flight hardware item.

**ECSS-E-ST-32-01\_0810058**

- b. The fracture control summary report shall contain the following:
  1. Summary of identified PFCI, FCI, FLLI and applied NDT methods, with specific reference to low risk fracture PFCI, pressurized PFCI, safe life fasteners, composite PFCI, bonded PFCI, sandwich PFCI, glass and other shatterable/brittle PFCI, other non-metallic PFCI, and detected defects that remain in PFCI.
  2. A summary discussion of alternative approaches or specialised assessment applied and tests performed.
  3. A statement that NDT or tests specified for fracture control were, in fact, applied in conformance with requirements, and that the proper use of the approved materials has been verified.
  4. A statement that hardware configuration of PFCI and their assemblies has been physically verified.
  5. References to supporting documentation.

NOTE For example, load spectra definitions, analysis reports, test reports, NDT reports, structural screening results and associated lists.

# 7

## Fracture mechanics analysis

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### 7.1 General

**ECSS-E-ST-32-01\_0810059**

- a. Fracture mechanics analysis shall be performed to determine the analytical life of a safe life metallic item.

**ECSS-E-ST-32-01\_0810060**

- b. The following data shall be made available in order to enable crack growth prediction and critical crack-size calculation:
  1. Stress distribution
  2. Load spectra
  3. Material properties
  4. Initial crack size
  5. Stress intensity factor solutions.

**ECSS-E-ST-32-01\_0810322**

- c. For the fracture mechanics analysis, the latest version of the software package ESACRACK may be used.

NOTE 1 Additional information on this software package can be found in Annex A, which also addresses some of the limitations of this software.

NOTE 2 In general, existing fracture control analysis is not updated for each new update of the ESACRACK software. Update of the existing analysis using the latest version is normally performed, for example, in cases where the analysis is used to support the acceptance of detected defects (see 10.7), or in specific cases where there is a clear indication that the existing analysis made with an older version can be inadequate.

**ECSS-E-ST-32-01\_0810062**

- d. In cases where the latest version of the software package ESACRACK is not used, the alternative methods used and their validation shall be submitted to the customer for approval prior to their use.

**ECSS-E-ST-32-01\_0810063**

- e. A fracture mechanics analysis shall include the following two items:
1. Crack-growth calculation in conformance with 7.2.
  2. Critical crack-size calculations in conformance with 7.3.

**NOTE** In most cases the fracture mechanics analysis demonstrates a margin on the required lifetime and crack size, based on initial crack sizes defined for standard or special fracture control NDT. For standard and special fracture control NDT, see in particular clause 9 of ECSS-Q-ST-70-15. As alternative, the critical (i.e., maximum) initial defect (CID) size for which the item can survive four times the required service life can be calculated iteratively, after which it can be verified by non-destructive testing that the probability of having cracks greater than or equal to this size is sufficiently small. This CID approach is specifically appropriate for analysis of cracks to be screened by proof testing. The CID approach can require careful scrutiny of the validity of the analysis, because it does not demonstrate any margin in the analysis results.

## 7.2 Analytical life prediction

### 7.2.1 Identification of all load events

**ECSS-E-ST-32-01\_0810064**

- a. The service-life profile of the item shall be defined in order to identify all cyclic and sustained load events to be included in the stress spectrum.

**ECSS-E-ST-32-01\_0810065**

- b. All load events expected for the item shall be included in the service-life profile.

**NOTE** Examples of load events expected throughout the service life are:

- manufacturing and assembly;
- testing (including re-testing if applicable);

- pressurisations on ground
- handling, e.g. by a dolly or a hoist;
- transportation by land, sea and air;
- ascent (launch);
- stay in orbit, including thermally induced loads and operational loads;
- descent (re-entry);
- landing.

ECSS-E-ST-32-01\_0810066

c. &lt;&lt;deleted&gt;&gt;

### **7.2.2 Identification of the most critical location and orientation of the crack**

ECSS-E-ST-32-01\_0810067

a. The most critical location and orientation of the crack on the item shall be identified for the analysis.

ECSS-E-ST-32-01\_0810068

b. To identify the most critical location, the following parameters shall be considered:

1. The maximum level of local stress.
2. The range of cycling stress.
3. Locations with high stresses or stress intensities.
4. Areas where material fracture properties can be low.
5. Stresses which, combined with the environment, result in reduced fracture resistance.
6. Stress-concentration, environmental and fretting effects.
7. Severity of stress spectrum.
8. Locations with small wall thickness, especially pressure vessels and pressurised structures for which leakage is not acceptable.

ECSS-E-ST-32-01\_0810069

c. In cases where the most critical location or orientation of the initial crack is not obvious, the analysis shall consider a sufficient number of locations and orientations.



### 7.2.3 Derivation of stresses for the critical location

**ECSS-E-ST-32-01\_0810070**

- a. For the critical location, as identified in 7.2.2, the principal stresses shall be derived which are caused by the load components which act on the item during the load events identified in 7.2.1.

NOTE For example, principal stresses due to translational and rotational accelerations, pressure, temperature and loads induced by adjacent structure.

**ECSS-E-ST-32-01\_0810071**

- b. The stresses shall be derived for the worst credible combination of all influencing aspects

NOTE For example, influencing aspects to be considered include: geometrical discontinuities and imperfections, manufacturing defects, residual stresses

### 7.2.4 Derivation of the stress spectrum

**ECSS-E-ST-32-01\_0810072**

- a. A stress spectrum shall be derived for the critical location identified in 7.2.2, based on the load events identified in 7.2.1 and the stresses derived in 7.2.3.

**ECSS-E-ST-32-01\_0810073**

- b. In the stress spectrum, the number of cycles in each step, and the upper and lower values of the stress components in each step shall be defined.

NOTE For example, stress components are remote tension stress, remote bending stress and pin bearing stress.

**ECSS-E-ST-32-01\_0810074**

- c. The stress spectrum shall be provided to the customer for approval.

## 7.2.5 Derivation of material data

### ECSS-E-ST-32-01\_0810075

- a. Material properties used in the analytical evaluation shall be valid for the anticipated environment, grain direction, material thickness, specimen width and load ratio (R).

NOTE Where the operational temperature range overlaps with the ductile to brittle fracture transition temperature range of the material, the variation of material behaviour as function of temperature effect over this temperature range is taken into account in the analysis.

### ECSS-E-ST-32-01\_0810076

- b. Mean values of crack growth rate ( $da/dN$ ,  $da/dt$ ) shall be used.

### ECSS-E-ST-32-01\_0810077

- c. Mean value of threshold stress intensity range ( $\Delta K_{th}$ ) shall be used.

### ECSS-E-ST-32-01\_0810078

- d. Lower boundary values shall be used, for:
1. Critical stress intensity factor,  $K_{Ic}$  or  $K_C$  (fracture toughness), and other residual strength related properties (e.g. flow stress).
  2. Environmentally controlled threshold stress intensity for sustained loading,  $K_{ISCC}$ .

### ECSS-E-ST-32-01\_0810079

- e. Lower boundary values shall be derived as follows:
1. values with a 90% probability and 95% confidence level of being exceeded (B-value as defined in DOT/FAA/AR-MMPDS), or
  2. in cases where insufficient test data are available:
    - (a) 70 % of the mean values, and
    - (b) no measured values are below 70 % of the mean value unless agreed with the customer.

### ECSS-E-ST-32-01\_0810080

- f. For the definition of the proof loading to be applied for identification of initial crack sizes, upper boundary values of the critical stress intensity factor,  $K_{Ic}$  or  $K_C$ , shall be derived as follows:
1. values with a 90 % probability and 95 % confidence level of not being exceeded (upper bound B-value),
  2. in cases where insufficient test data are available:
    - (a) 1,3 times the mean values, and

- (b) no measured values are above 1,3 of the mean value unless agreed with the customer.

**ECSS-E-ST-32-01\_0810081**

- g. For the derivation of the proof loading to be applied for identification of initial crack sizes, in the case of through cracks, and in case the elastic-plastic approach is applicable, a factor of 1,3 shall be applied to the complete K-R curve, or an equivalent factor 1,69 if the J-R curve is used.

**ECSS-E-ST-32-01\_0810082**

- h. For those materials where a significant reduction of the  $K_c$  for thin sheets is observed, the reduced value shall be used in the analysis.

NOTE This reduction of fracture toughness is not automatically accounted for in the ESACRACK software.

**ECSS-E-ST-32-01\_0810083**

- i. Mechanical testing of metallic materials shall be performed in conformance with ECSS-Q-ST-70-45.

## **7.2.6 Identification of the initial crack size and shape**

**ECSS-E-ST-32-01\_0810084**

- a. The initial crack shape shall be identified by considering the geometry of the item and the critical location, in line with Figure 7-1, Figure 7-2, and Figure 7-3.

**ECSS-E-ST-32-01\_0810085**

- b. The initial crack sizes used in the analysis shall be defined based on the NDT level or proof load screening used for the item.

NOTE See also clause 10 and ECSS-Q-ST-70-15.

**ECSS-E-ST-32-01\_0810086**

- c. Crack aspect ratios ( $a/c$ ) of 0,2 and 1,0 shall be considered in the analysis.

**ECSS-E-ST-32-01\_0810087**

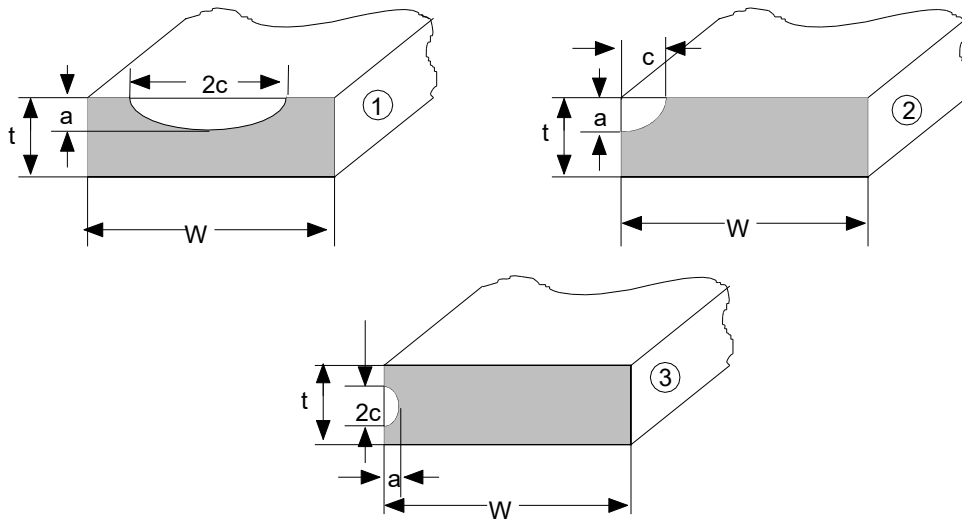
- d. An initial crack size as specified in 7.2.6e shall be assumed if all conditions below are met:
1. A large number of holes are drilled or the automatic hole preparation is used and NDT of holes cannot be performed.
  2. The load is not transmitted through a single hole, such as for a fitting.

3. The holes are not punched.
4. The material is not prone to cracking during machining.
5. NDT is performed prior to the machining of the holes.
6. No heat treatment or potentially crack forming fabrication processes are performed subsequent to NDT.
7. Approval is obtained from the customer.

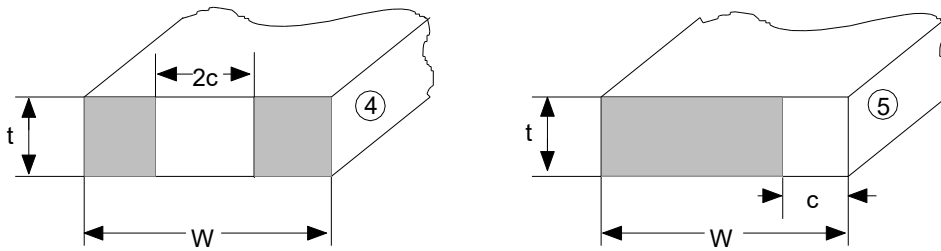
**ECSS-E-ST-32-01\_0810088**

- e. For automatic hole preparation indicated in 7.2.6d, an initial crack size shall be assumed based on the worst of the following:
  1. The initial crack size determined by the NDT performed before hole preparation, or
  2. The potential damage from hole preparation operations, as defined below:
    - (a) For drilled holes with driven rivets, the assumed defect due to potential damage is a 0,13 mm length crack through the thickness at one side of the hole.
    - (b) For fastener holes other than those for driven rivets, where the material thickness is equal to or less than 1,3 mm, the assumed fabrication defect due to potential damage is a 1,3mm length crack through the thickness at one side of the hole.
    - (c) For fastener holes other than those for driven rivets, where the thickness is greater than 1,3 mm, the initial crack size due to potential damage is a 1,3 mm radius corner crack at one side of the hole.

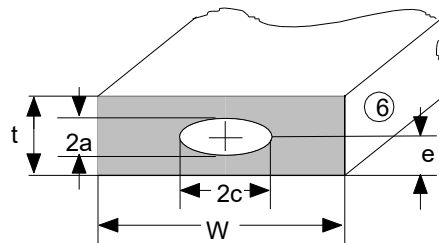
Part-through cracks



Through cracks

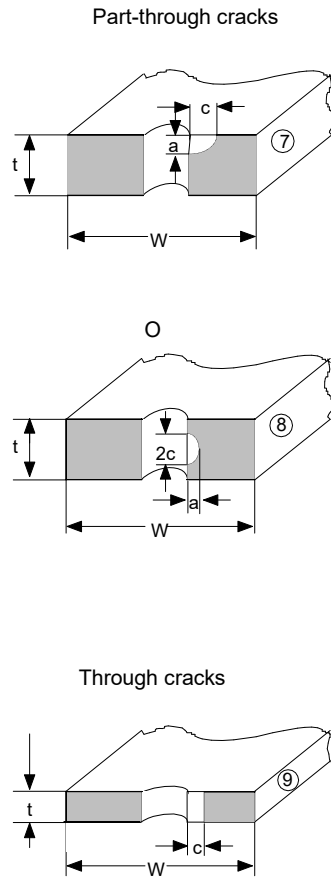


Embedded cracks



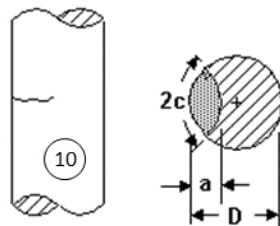
ECSS-E-ST-32-01\_0810313

Figure 7-1: Initial crack geometries for parts without hole



ECSS-E-ST-32-01\_0810314

**Figure 7-2: Initial crack geometries for parts with holes**



ECSS-E-ST-32-01\_0810315

**Figure 7-3: Initial crack geometries for cylindrical parts**

## 7.2.7 Identification of an applicable stress intensity factor solution

**ECSS-E-ST-32-01\_0810089**

- a. Stress intensity factor solutions for the relevant item geometry, crack shape, crack size and loading shall be used.

**ECSS-E-ST-32-01\_0810090**

- b. Local stresses caused by stress concentrations shall be included in the applied stress spectrum if their effect is not fully included in the used stress intensity factor solutions used in 7.2.7a.

## 7.2.8 Performance of crack growth calculations

**ECSS-E-ST-32-01\_0810091**

- a. Crack growth calculations shall be performed using the variables as defined in 7.2.1 to 7.2.7.

**ECSS-E-ST-32-01\_0810092**

- b. The analysis methodology used shall account for the two-dimensional growth characteristics of cracks, multiple loading events with variation in amplitude, excursions between mean stress levels and negative stress ratios.

**ECSS-E-ST-32-01\_0810093**

- c. The complete loading spectrum shall be analytically imposed at least four (4) times in sequence, one after another.

**ECSS-E-ST-32-01\_0810094**

- d. The loading spectrum shall be an envelope of all the credible load events that can be encountered during the design life.

**ECSS-E-ST-32-01\_0810095**

- e. Growth of cracks beyond the critical crack size shall not be considered in the crack growth analysis.

**ECSS-E-ST-32-01\_0810096**

- f. In cases where leakage is hazardous or otherwise specified as unacceptable by the customer, growth of cracks through the thickness shall not be considered in the crack growth analysis.

**ECSS-E-ST-32-01\_0810097**

- g. Beneficial retardation effects on crack growth rates from variable amplitude spectrum loading shall not be considered without the approval of the customer.

**ECSS-E-ST-32-01\_0810098**

- h. For components where a crack grows into a hole, the analysis shall assume that the crack propagation is not arrested or retarded by the hole.

**ECSS-E-ST-32-01\_0810099**

- i. For cyclic plastic deformation, EPFM crack-growth methodology shall be used, which is subject to customer approval.

**ECSS-E-ST-32-01\_0810100**

- j. For manufacturing steps, which can cause crack extension without the possibility of subsequent NDT the maximum possible crack growth shall be considered in the safe life calculation.

NOTE For example, the autofrettage pressure cycle during manufacturing of a COPV which can lead to crack growth by linear or non-linear material behaviour. Especially the non-linear material behaviour can lead to stable crack growth (ductile tearing) which can be considerably underestimated. More information on autofrettage can be found in [R8].

**ECSS-E-ST-32-01\_0810101**

- k. Shear (i.e. mode II or mode III) loading of the crack shall be considered, using an analysis method agreed with the customer.

## 7.3 Critical crack-size calculation

**ECSS-E-ST-32-01\_0810102**

- a. The critical crack-size ( $a_c$ ) shall be calculated by means of LEFM:

$$a_c = \frac{(K_c)^2}{\pi \sum (F_i S_i)^2}$$

where  $S_i$  are the maximum specified stresses and  $F_i$  are the stress intensity magnification factors for the different load cases (which depend on the crack size  $a$ ) and  $K_c$  is the critical stress intensity factor.

NOTE The maximum specified load is in many cases the limit load, but sometimes higher than the limit load (e.g. for detected defects, composites and glass items).



**ECSS-E-ST-32-01\_0810103**

- b. In those cases outside the range of validity of LEFM, the critical crack size shall be evaluated by appropriate EPFM methods or by a structure representative test.

NOTE 1 This applies also to crack extension under non-linear material behaviour. For example ductile tearing.

NOTE 2 The consideration of structure representative conditions is of great importance in the case of EPFM, where for example stress multi-axiality effects can significantly influence the results of the analysis or test.

NOTE 3 In the NASGRO module of the ESACRACK software a simplified verification can be performed to ensure that no premature failure under elastic-plastic conditions occurs, based on comparison of the so-called net-section stress and flow stress. In most of the common applications this can be considered as adequate. For e.g. verification of highly critical, highly stressed (e.g. pressure vessels, launcher tanks) applications and detected defects it can be necessary to performed more advanced EPFM analysis or testing.

**ECSS-E-ST-32-01\_0810104**

- c. The material properties used for the critical crack size calculation shall be in conformance with 7.2.5.

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# Special requirements

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## 8.1 Introduction

Except where it is explicitly specified that they replace requirements, these special requirements apply in addition to those specified in clauses 4 to 7 and 9 to 11.

## 8.2 Pressurized hardware

### 8.2.1 General

#### ECSS-E-ST-32-01\_0810105

- a. All pressurized systems in human spaceflight systems and payloads shall be in conformance with the requirements specified by the customer.

NOTE 1 Pressurized hardware (including pressure vessels, pressurized structures, pressure components, and special pressurized equipment) otherwise comply with ECSS-E-ST-32-02. Human spaceflight requirements like those applicable to the ISS or Exploration systems or payloads can go beyond those requirements.

NOTE 2 For the attachments of pressurized hardware, which are not part of the pressurized shell, no special requirements are specified in 8.2. They follow the normal rules of this standard (e.g. be verified safe life or fail safe) to prevent catastrophic hazards.

#### ECSS-E-ST-32-01\_0810337

- b. If the structural integrity is demonstrated by means of a proof test of the flight hardware, then for this approach to be valid the stresses induced by the proof testing shall envelope the pressure loads and any other loads contribution, unless the latter are below 30 % of UTS.

NOTE Example 8.2.4b, 8.2.6a, 11.2.2.8c.4.

**ECSS-E-ST-32-01\_0810338**

- c. If the structural integrity is demonstrated by means of NHLBB failure mode, then for this approach to be valid the stresses induced by the MDP shall be dominant.

NOTE 1 Other loads do not induce significant risk of crack growth by fatigue or sustained loading of a crack with 10 times the wall thickness (see ECSS-E-ST-32-02, 5.3.2).

NOTE 2 Example: 8.2.5a.2, 8.2.1b and 8.2.1c address the fact that the definition of pressurized hardware (ref. ECSS-E-ST-32-02) assumes that it 'primarily contains internal pressure'. Supports are addressed separately.

**ECSS-E-ST-32-01\_0810339**

- d. The user shall define the appropriate type of pressure, either absolute or differential, throughout the design and verification process, taking into account the environmental conditions.

NOTE As an example, if the operational MDP is defined in orbit, for the test on ground under ambient conditions, an additional internal pressure of 1 bar must be considered to achieve the proper differential pressure.

## 8.2.2 Pressure vessels

### 8.2.2.1 Overview

Pressure vessels are classified as fracture critical, in conformance with 6.2.2.

Pressure vessels are subject to the implementation of fracture critical item tracking, control and documentation procedures, in conformance with 10.6.

### 8.2.2.2 Requirements

**ECSS-E-ST-32-01\_0810106**

- a. In addition to the maximum design pressure (MDP), as defined in clause 3.1 of this standard, all external loads shall be included in the fracture control verification.

NOTE Example of external loads are vehicle acceleration loads.

**ECSS-E-ST-32-01\_0810107**

- b. Fracture mechanics verification of metallic pressure vessels and metallic liners of COPV shall, when required in conformance with ECSS-E-ST-32-02, be performed in conformance with Figure 8-1 and clauses 6.3.2 and 7.

NOTE ECSS-E-ST-32-02 also includes fracture control requirements for composite pressure vessels without liners or non-metallic liners.

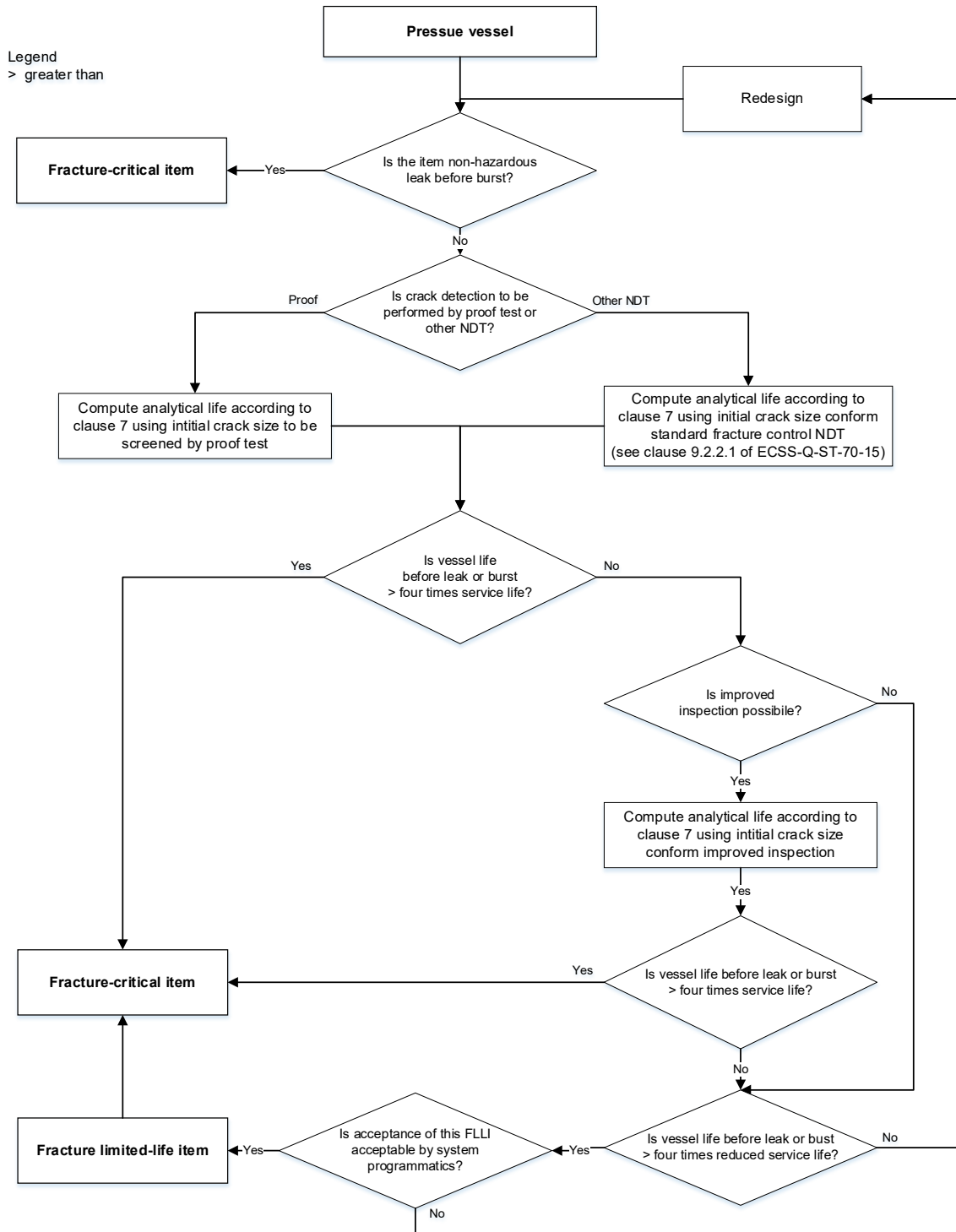
**ECSS-E-ST-32-01\_0810108**

- c. The verification of 8.2.2.2b, shall demonstrate safe life against hazardous leakage and burst.

**ECSS-E-ST-32-01\_0810109**

- d. For non-hazardous leak before burst (NHLBB) vessels, all areas which cannot be verified LBB, shall be verified as safe life.

NOTE For example, at load introduction (e.g. boss area) and in other thick-walled regions, when agreed with the customer.



ECSS-E-ST-32-01\_0810311

Figure 8-1: Procedure for metallic pressure vessel and metallic liner evaluation

## 8.2.3 Pressurized structures

### 8.2.3.1 General

**ECSS-E-ST-32-01\_0810110**

- a. A pressurized structure shall be classified as a fracture critical item, when any of the following applies:
1. It is the pressure shell of a manned module.
  2. It contains stored energy of 19310 joules (14240 foot-pounds) or more, the amount being based on the adiabatic expansion of a perfect gas.
  3. It contains a gas or liquid which creates a hazard if released.
  4. It is subjected to a maximum design pressure (MDP) greater than 0,69 MPa (100 psi).

**ECSS-E-ST-32-01\_0810111**

- b. Pressurized structures shall be in conformance with ECSS-E-ST-32-02, clause 4.4.

**ECSS-E-ST-32-01\_0810112**

- c. Pressurized structures conforming to ECSS-E-ST-32-02 which have composite overwrap or are fully made of composite shall not be implemented for human spaceflight missions without approval of the customer.

NOTE For such pressurized structures, see clauses 4.4.2, 4.4.3 and 4.4.4 of ECSS-E-ST-32-02.

**ECSS-E-ST-32-01\_0810113**

- d. Fracture mechanics verification of metallic pressurized structures and metallic liners of overwrapped pressurized structures shall, when required in conformance with 8.2.3.1b, be performed in conformance with clauses 6.3.2 and 7 of this Standard.

**ECSS-E-ST-32-01\_0810114**

- e. The verification of 8.2.3.1d, shall demonstrate safe life against hazardous leakage and burst.

### 8.2.3.2 Manned pressurized structures

**ECSS-E-ST-32-01\_0810115**

- a. The design of manned pressurized structures shall be in conformance with the LBB criterion, in conformance with ECSS-E-ST-32-02, clause on "Failure mode demonstration".

**ECSS-E-ST-32-01\_0810116**

- b. The design shall be safe life to leakage.

## 8.2.4 Pressure components, including lines and fittings

ECSS-E-ST-32-01\_0810117

- a. For pressure components, including lines and fittings, the complete pressure system shall be proof tested and leak checked in addition to an acceptance proof test of the individual items.

ECSS-E-ST-32-01\_0810323

- b. Safe life analysis may be omitted if the item is proof tested to a level of 1,5 or more times the limit load, including MDP and vehicle accelerations.

NOTE A successful proof test does not inherently guarantee leak tight performance for components subjected to a significant fatigue environment (e.g. operational pressure fluctuations, external loads) that can affect fatigue performance in the presence of allowable defects and weld geometry.

ECSS-E-ST-32-01\_0810119

- c. All fusion joints shall be 100 % non-destructive tested by means of a qualified NDT method.

ECSS-E-ST-32-01\_0810120

- d. Concurrence of the customer shall be obtained where 100 % NDT is not considered practicable.

ECSS-E-ST-32-01\_0810340

- e. For non-hazardous LBB pressurized hardware, the requirements of clause 8.2.7 shall be applied instead of 8.2.4a to d.

## 8.2.5 Low risk sealed containers

ECSS-E-ST-32-01\_0810341

- a. Sealed containers meeting the following criteria may be used:
  1. The container is not part of a system with a pressure source and is individually sealed.
  2. Leakage of the contained gas does not result in a catastrophic hazard and the pressure shell is verified leak before burst (LBB) at MDP.
  3. The part is manufactured from metal alloys used for commercially available sealed containers procured to an aerospace standard or equivalent that are not susceptible to crack extension related to SCC.
  4. The MDP does not exceed 0,15 MPa.

5. The stored energy potential does not exceed 19310 joules (14240 foot-pounds).
6. The container does not have an impervious barrier or coating that inhibits leakage on either the interior or exterior surfaces.
7. The container is subject to the following:
  - (a) Tested for leaks before repressurization.
  - (b) Re-flight containers are tested for leaks before being re-flown.

**ECSS-E-ST-32-01\_0810342**

- b. For sealed containers with a MDP higher than 0,15 MPa (22 psi), but less than 0,30 MPa (44 psi), meeting criteria 8.2.5a.1, 8.2.5a.2, 8.2.5a.3, 8.2.5a.5, 8.2.5a.6 and 8.2.5a.7, additional fracture assessment need not be performed if the following apply:
  1. the minimum factor of safety is  $2,5 \times \text{MDP}$  (verified by stress analysis or test), or
  2. the container is proof-tested to a minimum of  $1,5 \times \text{MDP}$

**ECSS-E-ST-32-01\_0810123**

- c. All sealed containers shall be capable of sustaining 0,10 MPa (15 psi) pressure difference with a minimum safety factor of 1,5.

## 8.2.6 Hazardous fluid containers

**ECSS-E-ST-32-01\_0810124**

- a. Hazardous fluid containers shall comply with the following:
  1. Have a stored energy of less than 19310 Joules (14240 foot-pounds) with an internal pressure of less than 0,15 MPa (22 psi).
  2. Have a minimum safety factor of 2,5 times MDP.
  3. Be in conformance with the fracture control requirements for pressure components specified in clause 8.2.4.
  4. When agreed with the customer not to use a proof test to a minimum factor of 1,5, safe-life can be assured by NDT application and crack growth analysis.
  5. Integrity against leakage is verified by test at a minimum pressure of 1,0 times MDP.

NOTE to item 3: this includes weld NDT.

**ECSS-E-ST-32-01\_0810125**

- b. If provision 8.2.6a is not met, hazardous fluid containers shall:
  1. Have safe-life against rupture and leakage.
  2. Be treated and certified the same as pressure vessels when the contained fluid has a delta pressure greater than one atmosphere.



## 8.2.7 Pressurized components with non-hazardous LBB failure mode

ECSS-E-ST-32-01\_0810343

- a. A NHLBB pressure component shall satisfy the following:
1. The LBB failure mode is demonstrated at MDP in accordance with clause 5.3 of ECSS-E-ST-32-02.
  2. The leak does not cause a catastrophic hazard.
  3. As the component leaks down, there is no repressurization or continued pressure cycles that can lead to continued fatigue or crack growth related to sustained loading.
  4. The hardware is manufactured from metal alloys that are not susceptible to crack growth related to sustained loading in the applicable environment and that are typically used for pressurized systems, using processes that have been established by reliability or investigations of many similar parts to be unlikely to produce parts with a flaw exceeding process specifications.
  5. Associated structure supporting the pressure component also meets fracture control requirements.
  6. The component does not have an impervious barrier, coating, on either the interior or exterior surfaces that inhibits leakage.
  7. Re-flight hardware is tested for leaks before repressurization and before being re-flown.

## 8.3 Welds

### 8.3.1 Nomenclature

ECSS-E-ST-32-01\_0810126

- a. The standardised nomenclature for the different types of welds and their characteristics, including imperfections, as presented in ISO 17659 and EN ISO 6520-1 shall be used where applicable.

NOTE Cases not directly covered by ISO 17659 and EN ISO 6520-1 are addressed on a case-by-case basis as agreed between customer and supplier. Example: ECSS-Q-ST-70-39 for friction stir welding.

### 8.3.2 Safe life analysis of welds

#### ECSS-E-ST-32-01\_0810127

- a. For welds, the fracture mechanics analysis shall be performed with the aid of the material properties of the weldments, including weldment repairs.

#### ECSS-E-ST-32-01\_0810128

- b. When the material properties specified in 8.3.2a are not available, they shall be derived by means of a test programme to the extent necessary to complement the fracture mechanics analysis in 8.3.2d, and covering:
1. Ultimate and yield strength for all welding conditions needed as input to the analytical assessment, including mechanical properties (as in 8.3.2a) in the presence of different misalignments, angles between joints or typical defects, and their consequences.
  2. Fracture toughness  $K_{IC}$ , stress-corrosion cracking threshold  $K_{ISCC}$ , and crack propagation parameters for each type of thickness.
  3. Young's modulus for weld material:
    - (a) Evaluated by test only in those cases, where a significant amount of a second phase with a different modulus compared to the base material appears.
    - (b) If the microstructure with respect to the different phases does not change, the base material Young's modulus applies also for weld material.

#### ECSS-E-ST-32-01\_0810129

- c. The test programme specified in 8.3.2b shall be performed on a number of specimens agreed with the customer, but not less than 5, in order to permit a statistical evaluation of final values.

#### ECSS-E-ST-32-01\_0810130

- d. The fracture mechanics assessment shall be performed under consideration of any potential weld geometrical imperfection as follows:
1. In a first step, a screening of the applied weld process and material is performed to identify all potential weld geometrical imperfections.
  2. Acceptance limits for the identified geometrical imperfections are determined and included in the fracture mechanics analysis.

NOTE To item 1: See for example EN ISO 6520-1 as defined in 8.3.1a.

#### ECSS-E-ST-32-01\_0810131

- e. Any residual stresses, both in the weld and in the heat-affected zone, shall be used in the safe life analysis.

**ECSS-E-ST-32-01\_0810132**

- f. Except in the case specified in 8.3.2g, even though non-destructive tested for embedded flaws and pores, the initial crack geometry for the analysis shall always be assumed to be a surface part-through-crack or through-crack, as specified in clause 10 and ECSS-Q-ST-70-15.

**ECSS-E-ST-32-01\_0810133**

- g. Embedded crack cases shall not be used in cases other than those where NDT methods are used which enable the determination of the relative distance of the embedded flaw to the surface.

NOTE For example, embedded cracks (see Figure 7-1 geometry 6) can be used when ultrasonic inspection is applied.

## 8.4 Composite, bonded and sandwich structures

### 8.4.1 General

**ECSS-E-ST-32-01\_0810134**

- a. <<deleted>>

**ECSS-E-ST-32-01\_0810135**

- b. All PFCI falling into the category fibre-reinforced composites, bonded and sandwich structures shall comply with clauses 8.4.2 to 8.4.4.

NOTE 1 This includes adhesive bonds in metallic structures.

NOTE 2 PFCI made of fibre-reinforced composite, including bonded joints, sandwiches and potted inserts, which are classified safe life and which are not low-risk fracture items in conformance with 8.4.4.3, are treated as fracture critical items, in conformance with 6.2.2.

**ECSS-E-ST-32-01\_0810136**

- c. Composite overwraps of COPV and other composite overwrapped pressurized hardware shall be in conformance with clause 8.2 and ECSS-E-ST-32-02, as minimum.

NOTE 1 This means that these composite PFCI do not need to be fully compliant with the detailed requirements of this clause 8.4.

NOTE 2 For the attachments of pressurized hardware, which are not part of the pressurized shell, no special requirements are specified in 8.2 and ECSS-E-ST-32-02. Composite, bonded and sandwich attachment hardware follows the rules of this clause 8.4 to prevent catastrophic hazards.

## 8.4.2 Defect assessment

### 8.4.2.1 Manufacturing defects

**ECSS-E-ST-32-01\_0810137**

- a. A list of potential manufacturing defects, including their maximum acceptable size (or ratio for porosity), shall be established, covering all applied manufacturing processes.

NOTE For example, the following defects, depending on the manufacturing process, can be considered:

- High porosity ratio
- Delamination
- Fibre misalignment
- Cut or broken fibres
- Joint debonding.

**ECSS-E-ST-32-01\_0810138**

- b. The maximum acceptable defect size (or ratio) considered in the verification shall be detectable by the applied NDT, in conformance with 10.3 and ECSS-Q-ST-70-15.

NOTE 1 With approval of the customer, acceptable defect size (or ratio) consistent with the manufacturing process (including process control) are sometimes used in the fracture control verification for certain manufacturing defect types, instead of defects based on NDT.

NOTE 2 The complete ECSS-Q-ST-70-15 applies, but clause 9.3 is of particular relevance to PFCI made of composite, bonded and sandwich materials.

**ECSS-E-ST-32-01\_0810139**

- c. The effects of the potential manufacturing defects on the structural integrity shall be established, documented and verified.

NOTE Examples of such effects are strength, stability, and fatigue.

**ECSS-E-ST-32-01\_0810140**

- d. Acceptance criteria based on a fracture control methodology, as defined in this clause 8.4, shall be established for those manufacturing defects for which the effect is not already included in material properties used for structural design and qualification.

NOTE For example, in conformance with 8.4.2.1c and 8.4.2.1d porosity can be excluded from

verification by means of a fracture control methodology, if the detectable ratio by means of NDT is fully represented in the derivation of strength and fatigue allowables.

#### 8.4.2.2 Mechanical damage

**ECSS-E-ST-32-01\_0810141**

- a. Mechanical damage shall be considered in conformance with the damage threat assessment as specified in clause 8.4.3

NOTE For example, the following mechanical damage due to events which can occur during the service life, can be considered:

- Impact
- Scratch
- Abrasion.

#### 8.4.2.3 Defect assessment procedures

**ECSS-E-ST-32-01\_0810142**

- a. The following types of defects shall be included in the safe life verification in conformance with 8.4.4.2:

1. Mechanical damage at the maximum expected level, as specified in clause 8.4.4.2 and 8.4.3.
2. Manufacturing defects at the maximum size (or ratio) in conformance with applied NDT methods as specified in clause 8.4.2.1.
3. Detected defects in conformance with clause 10.7.

**ECSS-E-ST-32-01\_0810143**

- b. For fail safe verification in conformance with 8.4.4.1, detected defects shall be included in conformance with clause 10.7.

**ECSS-E-ST-32-01\_0810144**

- c. Low-risk fracture verification in conformance with 8.4.4.3 shall consider the damage associated with the visual damage threshold (VDT) or larger.

NOTE For detected defects in low-risk fracture items, see clause 10.7.

## 8.4.3 Damage threat assessment

### 8.4.3.1 Introduction

The objectives of the damage threat assessment are to:

- Determine the upper level of mechanical damage which is taken into account in the safe life verification.
- Ensure that the verification of fail-safe and low-risk fracture items is based on valid assumptions, i.e.: to consider only detected defects for fail safe items, and VDT for low-risk fracture items.

The damage threat assessment takes into account damage protection, NDT and indication performed throughout the service life of the item.

The damage threat assessment is also applied to those safe life items screened for manufacturing defects by proof testing, in conformance with 8.4.4.2g, to ensure that no detrimental damage occurs after proof testing.

### 8.4.3.2 Identification of potentially damaging events and resulting mechanical damage

**ECSS-E-ST-32-01\_0810145**

- a. The events that can cause mechanical damage during the service life, shall be identified and documented in the fracture control analysis report.

NOTE 1 The service life includes the following phases:

- Handling,
- Test,
- Transportation,
- In-service use,
- Maintenance,
- The manufacturing phase, which are not covered by NDT.

NOTE 2 The following are examples of credible events:

- Tool drop
- Bumping or falling during handling
- Scratch during assembly.

**ECSS-E-ST-32-01\_0810146**

- b. For the events identified in 8.4.3.2a the type and maximum credible magnitude of the associated threats to the integrity of the hardware during those events shall be identified.

NOTE For example, the magnitude of the threat can be described by the energy at impact, the shape, material and orientation of the impactor and the worst impact location.

**ECSS-E-ST-32-01\_0810147**

- c. The assessment shall include the potential consequences of impact of items considered as low mass or low momentum (in conformance with 6.1), or due to items considered as contained or restrained (in conformance with 6.3.4), in case they are released.

**ECSS-E-ST-32-01\_0810148**

- d. For the type and maximum magnitude of the threat during each event that can cause mechanical damage, as identified in 8.4.3.2a, 8.4.3.2b and 8.4.3.2c, the resulting mechanical damage shall be identified with its type and size or level.

NOTE 1 Types of damage are for example: impact damage (including delamination, broken fibres and perforation), scratch, and abrasion.

NOTE 2 Damage size or level can be characterised, for example, by energy level for impact, or depth and length for a scratch.

**8.4.3.3 Mechanical damage protection****ECSS-E-ST-32-01\_0810149**

- a. In the case where protective devices are used to reduce the effects of events, to avoid some events, or to protect the structure, the effectiveness of the devices shall be demonstrated by test.

**8.4.3.4 Mechanical damage NDT and indicators****ECSS-E-ST-32-01\_0810150**

- a. Close visual testing shall be performed for each PFCI and FCI, just before each launch or just before closeout of surrounding structure after which mechanical damage is no longer credible, as determined in 8.4.3.2.

**ECSS-E-ST-32-01\_0810151**

- b. NDT shall meet the requirements of clause 10.3 and ECSS-Q-ST-70-15.

**ECSS-E-ST-32-01\_0810152**

- c. In case mechanical damage indicators are applied to provide positive evidence of a mechanical damage event, their effectiveness shall be demonstrated by test.

## 8.4.4 Compliance procedures

### 8.4.4.1 Fail safe items

**ECSS-E-ST-32-01\_0810153**

- a. A fail safe item shall meet all the requirements for the fail safe approach described in clauses 6.2, 6.3, and 10.7.

**ECSS-E-ST-32-01\_0810154**

- b. For a fail safe item it shall be demonstrated by test or analysis supported by test that there is no unacceptable degradation (in conformance with 8.4.4.1a) of the alternative load path, due to cyclic loads or environmental effects.

NOTE No damage needs to be considered for the alternative load path, unless detected defects exist (see clause 8.4.2.3).

**ECSS-E-ST-32-01\_0810155**

- c. A fail safe item shall be inspected at least by close visual testing covering hundred per cent of the item before each flight, in addition to NDT during manufacturing.

### 8.4.4.2 Safe life items

**ECSS-E-ST-32-01\_0810156**

- a. A safe life item shall meet all the requirements for the safe life approach described in clauses 6.2, 6.3, and 10.7.

NOTE See also Figure 6-4.

**ECSS-E-ST-32-01\_0810157**

- b. For a safe life item the requirements of 8.4.4.2a shall be satisfied by full-scale or sub-scale tests complemented by coupon testing, or analysis supported by tests representative of structural details.

**ECSS-E-ST-32-01\_0810158**

- c. For a safe life item the tests of 8.4.4.2b shall be performed in the presence of induced defects representative of manufacturing defects (in conformance with 8.4.2.1) and mechanical damage as defined in 8.4.4.2d, as specified in 8.4.2.3.

NOTE The use of interlaminar fracture mechanics analysis is submitted to customer approval and includes the successful demonstration of the methodology by test on sub-component or component (structure) level.



**ECSS-E-ST-32-01\_0810159**

- d. The most severe of the following mechanical damage shall be considered for verification of safe life items:
1. The maximum size or level that can be induced, in conformance with 8.4.3.2 and 8.4.3.3, and remain undetected, in conformance with 8.4.3.4.
  2. Mechanical damage resulting from impact energy associated with the visual damage threshold.

**ECSS-E-ST-32-01\_0810160**

- e. For a safe life item the test articles and tests of the test program of 8.4.4.2b shall be representative of manufacturing process, environment and loading type (considering local load introduction where applicable) demonstrating ultimate load capability and no growth of defects at the end of one time the service life with a load enhancement factor (LEF) of 1,15.

NOTE Test articles can be flight representative structural elements, (sub)components or full-scale parts.

**ECSS-E-ST-32-01\_0810161**

- f. For a safe life item the test programme (including applied LEF and fatigue spectrum) shall be approved by the customer;

**ECSS-E-ST-32-01\_0810324**

- g. For a safe life item, a proof test for manufacturing defect screening may be applied when:
1. It is subjected to customer approval.
  2. A proof test factor of at least 1,2 is applied to the limit loads.
  3. For multi-mission hardware, the proof test is repeated between flights.
  4. The applied proof loads do not exceed 80 % of the ultimate strength.
  5. Post test NDT is applied for all proof tested composite, bonded and sandwich parts.

NOTE 1 To item 2: The effect of material degradation due to environmental exposure is treated on a case by case basis. It can result in a higher proof test factor, which is agreed with the customer.

NOTE 2 To item 2: A large number of complicated load cases can be necessary to ensure that all locations of the structure are adequately screened for manufacturing defects during the proof testing. Simplification of the proof load cases can result in higher test loads, overdesign

of the flight structure and increased risk of failure during the test.

NOTE 3 To item 5: Special problems can arise in certain instances such as a region of high load transfer where compliance with the proof test requirements for the composite structure introduces local yielding of the metal component. These are treated on a case by case basis.

#### 8.4.4.3 Low-risk fracture items

##### ECSS-E-ST-32-01\_0810163

- a. A low-risk fracture item shall not be a pressure vessel, high energy rotating machinery, habitable module or otherwise fracture critical pressurized structure, and not contain a hazardous fluid.

##### ECSS-E-ST-32-01\_0810164

- b. For a low-risk fracture item, the result of the damage threat assessment shall be that, as a result of damage NDT and protection, no damage larger than the visual damage threshold is expected.

##### ECSS-E-ST-32-01\_0810165

- c. A low-risk fracture item shall be inspected, as a minimum, by close visual testing covering hundred per cent of the item before each flight, in addition to NDT during manufacturing.

##### ECSS-E-ST-32-01\_0810166

- d. A low-risk fracture item shall not include a single point failure bonded area.

##### ECSS-E-ST-32-01\_0810167

- e. For a low-risk fracture item the strain at the limit load shall be below the damage tolerance threshold strain.

##### ECSS-E-ST-32-01\_0810325

- f. With approval of the customer, it may be considered that the strain is below the damage tolerance threshold strain without specific testing, when:
  - 1. At the limit load the maximum tensile stresses, taken into account the stress concentration factor, is lower than 40 % of the material ultimate capability.
  - 2. At the limit load the maximum compressive stresses, taken into account the stress concentration factor, is lower than 25 % of the material ultimate capability.

## 8.5 Non-metallic items other than composite, bonded, sandwich and glass items

**ECSS-E-ST-32-01\_0810169**

- a. <<deleted>>

**ECSS-E-ST-32-01\_0810170**

- b. Fracture control implementation for PFCI made of non-metallic material shall be subject to customer approval.

NOTE Potential fracture critical items made of non-metallic material, other than those covered by clause 8.4 (composite, bonded and sandwich items) and clause 8.7 (glass), which are safe life, are treated as fracture critical items, in conformance with 6.2.2. For example, ceramic, C/SiC, C/C.

**ECSS-E-ST-32-01\_0810171**

- c. An item shall not be accepted as a fail safe item unless it meets the following two conditions:
1. It meets all the requirements for the fail safe approach described in clauses 6.2 and 6.3.
  2. It has been demonstrated that, for the item, there is no unacceptable degradation of the alternative load path, due to cyclic loads or environmental effects.

**ECSS-E-ST-32-01\_0810172**

- d. An item shall not be accepted as a safe life item unless it meets the following two conditions:
1. It has been demonstrated by fatigue analysis (accounting for the effects of cyclic and sustained loading) supported by tests that, during a time period of four times the service life, there is no unacceptable degradation due to cyclic loads or environmental effects in the presence of induced defects, compatible with applied NDT techniques, using representative coupons.
  2. It undergoes a proof-test of all flight hardware to not less than one and two tenth (1,2) times the limit load.

NOTE To item 1: Results of representative earlier tests can be used to support the analysis, when approved by the customer.

**ECSS-E-ST-32-01\_0810173**

- e. In those cases where problems arise to fulfil the proof test requirement, these shall be treated on a case by case basis.

NOTE For example, the region of high load transfer where compliance with the proof test requirements for the non-metallic structure introduces yielding of the metal component.

**ECSS-E-ST-32-01\_0810174**

- f. Test loads on the non-metallic item shall not exceed 80% percent of ultimate strength.

## 8.6 Rotating machinery

**ECSS-E-ST-32-01\_0810175**

- a. Rotating machinery shall be proof (spin) tested and subjected to NDT before and after proof testing.

**ECSS-E-ST-32-01\_0810176**

- b. The proof test factor shall be derived by means of fracture mechanics analysis, but not be less than 1,1.

NOTE Rotating hardware not considered as rotating machinery in conformance with 3.2.32 is treated as any structural item.

## 8.7 Glass components

**ECSS-E-ST-32-01\_0810177**

- a. The verification of all potential fracture critical glass components, except those verified as fail-safe or contained, shall include an analysis of crack growth under conditions of the stresses and the environments encountered during their service life.

**ECSS-E-ST-32-01\_0810178**

- b. A fracture mechanics analysis for potential sustained crack growth ( $da/dt$ ) shall be performed in conformance with clauses 7, 8.7c, 8.7d, 8.7e and 8.7f for each safe life glass item, in order to demonstrate that the item sustains after four (4) times its service life at least one and four tenths (1,4) times the limit load without fracture.

**ECSS-E-ST-32-01\_0810179**

- c. The sustained crack growth analysis shall apply factors to the sustained stresses of the stress spectrum as specified in Table 8-1, depending on the duration of each load event that induces sustained stress.

**ECSS-E-ST-32-01\_0810180**

- d. The initial crack depth used for design and analysis of glass items shall:
1. Not be smaller than three (3) times the detectable flaw depth based on the NDT methods used.
  2. Be subject to approval by the customer.

**ECSS-E-ST-32-01\_0810181**

- e. The smallest crack aspect ratio used for analytical life predictions shall be  $a/c = 0,1$ .

**ECSS-E-ST-32-01\_0810182**

- f. Crack growth properties at 100 % moisture shall be used for life predictions.

**ECSS-E-ST-32-01\_0810183**

- g. Proof testing or NDT, consistent with the loading expected during service life, shall be conducted to screen for manufacturing flaws in each potential fracture-critical glass item based on the result of the fracture mechanics analysis, with the following conditions:
1. Proof testing is performed for acceptance of pressurized glass components (such as windows and viewports) to screen the flaws larger than the initial crack depth, with minimum proof pressure of two (2) times the MDP.
  2. Proof testing is performed in an environment suitable to limit flaw growth during test.
  3. Humidity and encapsulated water is removed from the surface of the glass before proof testing.

NOTE Encapsulated water can be accumulated during  
e.g. storage before proof testing

**ECSS-E-ST-32-01\_0810326**

- h. If a factor of safety on strength of 5 or greater can be shown, and if approved by the customer, the proof test in conformance with 8.7g.1 may be omitted.

**ECSS-E-ST-32-01\_0810185**

- i. It shall be demonstrated that glass inside a habitable area is safe from breakage by safe life verification in conformance with 8.7b, or is contained, or that released particles are smaller than 50  $\mu\text{m}$ .

**Table 8-1: Factor on stress for sustained crack growth analysis of glass items**

Duration of sustained stress event	Factor on stress
life $\leq$ 1 week	1,4
1 week < life $\leq$ 1 month	1,3
1 month < life $\leq$ 1 year	1,2
life > 1 year	1,1
NOTE The factor on stress is larger for shorter design life because of the flaw growth velocity sensitivity to small variations in the stress intensity	

## 8.8 Fasteners

**ECSS-E-ST-32-01\_0810186**

- a. Fasteners smaller than diameter 5 mm (or 3/16") shall not be used in safe life applications.

**ECSS-E-ST-32-01\_0810187**

- b. Titanium alloy fasteners shall not be used in safe life applications.

**ECSS-E-ST-32-01\_0810188**

- c. All potential fracture-critical fasteners shall be procured and tested in conformance with aerospace standards for structural fasteners or equivalent specifications agreed with the customer.

NOTE For example, LN, AIR and NAS standards, or ISO, EN and national standards which are explicitly intended for aerospace applications.

**ECSS-E-ST-32-01\_0810189**

- d. Fasteners procured and tested in conformance with aerospace standards for non-structural fasteners shall not be used.

NOTE For those secondary connections where significant redundancy exists and fatigue is not a major concern, sometimes such non-structural fasteners are applied. This is agreed with the customer on a case by case basis.

**ECSS-E-ST-32-01\_0810190**

- e. All safe life fasteners shall be marked and stored separately following NDT or proof testing.

**ECSS-E-ST-32-01\_0810191**

- f. Safe life fasteners shall be non-destructive tested by the eddy current method in the shank, head fillet, and thread areas.

**ECSS-E-ST-32-01\_0810192**

- g. The standard fracture control NDT crack size to be considered in the thread and fillet area for the safe life fasteners, inspected as required in 8.8f, shall be  $a = c = 1,27$  mm when the inspection is in accordance with ECSS-Q-ST-70-15 standard eddy current fracture control NDT as shown in Figure 7-3.

NOTE This assumes rolled thread and fillet, in conformance with 8.8c.

**ECSS-E-ST-32-01\_0810193**

- h. Application of rivets shall conform to the requirements for fail-safe items of clause 6.3.3.

NOTE Rivets are permanently deformed during their installation, and therefore cannot be adequately non-destructive tested for cracks in the installed condition.

## 8.9 Alloys treated with electric discharge manufacturing (EDM)

**ECSS-E-ST-32-01\_0810344**

- a. In case of application of EDM on metallic alloys parts that are identified as PFCI the fracture and fatigue mechanical properties of the part shall be verified.

**ECSS-E-ST-32-01\_0810345**

- b. The justification logic for the use of EDM on metallic alloys PFCIs (or later FCIs) shall be described in the Fracture Control Plan and submitted to customer approval.

## 9

# Material selection

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### ECSS-E-ST-32-01\_0810194

- a. Materials shall be selected and controlled in conformance with ECSS-Q-ST-70 “Materials, mechanical parts and processes”.

NOTE The material selection process takes into account structural and non-structural requirements. The materials selected possess the appropriate fracture toughness, crack-growth characteristics, and structural properties, such as Young’s modulus and yield strength, in specified environmental conditions.

### ECSS-E-ST-32-01\_0810195

- b. Where validated properties for analysis are not available, or available properties are not validated by standard or other test procedures agreed with the customer, the statistical basis for average and minimum values shall be established by tests.

### ECSS-E-ST-32-01\_0810196

- c. For applications where failure of a material can result in catastrophic hazard, alloys which possess high resistance to stress-corrosion cracking in conformance with Table 5-1 (Alloys with high resistance to stress-corrosion cracking) of ECSS-Q-ST-70-36 shall be used.

NOTE Strength, fracture and fatigue properties for a large number of aerospace materials are documented in the ESA developed materials database “FRAMES-2”, which can be obtained from Mechanical Systems Department, ESA.

Further examples of frequently used sources for material data are the Metallic Materials Handbook (DOT/FAA/AR-MMPDS) and Aerospace Structural Metals Handbook (CINDAS/Purdue)



# 10

## Quality assurance and NDT

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### 10.1 Overview

For quality assurance requirements see ECSS-Q-ST-20 “Quality assurance”. For materials selection and quality control requirements see ECSS-Q-ST-70 “Materials, mechanical parts and processes”.

### 10.2 Nonconformances

**ECSS-E-ST-32-01\_0810197**

- a. For dispositioning of nonconformances for PFCIs, a reassessment of these items to verify conformance with the fracture control requirements shall be performed.

NOTE For nonconformances control see ECSS-Q-ST-10-09.

**ECSS-E-ST-32-01\_0810198**

- b. All nonconformances which affect fracture-critical items and primary structural hardware designed to safe life principles shall be dispositioned as “major nonconformances”.

### 10.3 NDT of PFCI

#### 10.3.1 General

**ECSS-E-ST-32-01\_0810199**

- a. All PFCI shall be subject to an NDT programme in conformance with ECSS-Q-ST-70-15, in order to validate the analytical life predictions and to permit hardware to be released as acceptable.

NOTE The complete ECSS-Q-ST-70-15 applies, but clause 9 is of particular relevance to fracture control and PFCI.

**ECSS-E-ST-32-01\_0810200**

- b. NDT shall be performed for the complete items, or as far as possible if full NDT is not possible, subject to customer approval.

NOTE The NDT to be applied to an item (or region of an item) is based on the most critical location of the item (or region of the item).

**ECSS-E-ST-32-01\_0810201**

- c. Detected defects shall be treated as specified in clause 10.7.

**ECSS-E-ST-32-01\_0810202**

- d. NDT shall be implemented for limited life items, as needed.

**ECSS-E-ST-32-01\_0810203**

- e. <<deleted and moved to ECSS-Q-ST-70-15>>

**ECSS-E-ST-32-01\_0810204**

- f. Verification of structural redundancy for fail-safe items shall be performed before each flight.

**ECSS-E-ST-32-01\_0810205**

- g. Post test NDT shall be performed for all proof-tested items, where the proof test is not the NDT method.

NOTE 1 With approval of the customer, the post test NDT can focus on areas with increased probability of defects, e.g. focusing on welds, castings, forgings, bonds, and composite parts.

NOTE 2 For reduced fracture control program see clause 11.2.2.8 and requirement 10.3.1p.

**ECSS-E-ST-32-01\_0810206**

- h. NDT of all welds shall include a search for surface flaws as well as embedded flaws.

NOTE For reduced fracture control program see clause 11.2.2.8 and requirement 10.3.1p.

**ECSS-E-ST-32-01\_0810207**

- i. 100 % NDT of all fusion joints of pressurized lines shall be performed before and after proof test, using a qualified NDT method.

NOTE 1 After proof testing the NDT can be limited to 100% surface flaw NDT, and non-destructive re-testing of areas with detected pores/porosity, if agreed by the customer.

NOTE 2 For reduced fracture control program see clause 11.2.2.8 and requirement 10.3.1p.

**ECSS-E-ST-32-01\_0810208**

- j. NDT requirements shall be stated on design and manufacturing documentation.

**ECSS-E-ST-32-01\_0810209**

- k. <<deleted (moved to ECSS-Q-ST-70-15)>>

**ECSS-E-ST-32-01\_0810210**

- l. <<deleted (moved to ECSS-Q-ST-70-15)>>

**ECSS-E-ST-32-01\_0810211**

- m. Dedicated jigs, fixtures and equipment needed to perform non-destructive re-testing after delivery shall be delivered with fracture-critical items.

**ECSS-E-ST-32-01\_0810236**

- n. Special fracture control NDT shall be used only in special cases where limited life is demonstrated for standard initial crack sizes and serious problems can occur as a result of redesign or acceptance of the limited life, and its application is subject to approval by the customer.

NOTE For special fracture control NDT, see in particular clause 9 of ECSS-Q-ST-70-15.

**ECSS-E-ST-32-01\_0810346**

- o. The cases where proof test monitoring by acoustic emission can be performed instead of post testing NDT shall be agreed with the customer.

NOTE The proof test can be used to screen for manufacturing defects as specified in clause 8.4.4.2.

**ECSS-E-ST-32-01\_0810347**

- p. For the reduced fracture control program requirements 10.3.1g, 10.3.1h and 10.3.1i may be replaced by requirements from clause 11.2.2.8.

NOTE Alternatively, 8.2.7 "Pressurized components with non-hazardous LBB failure mode" can offer a way to limit the inspection effort requested for fracture control verification.

### 10.3.2 NDT of raw material

**ECSS-E-ST-32-01\_0810212**

- a. Raw materials for all safe life, fail-safe and low-risk fracture items shall be non-destructive tested in conformance with ECSS-Q-ST-70-15, to

ensure conformance with the general material quality specification and absence of unacceptable embedded flaws.

NOTE The complete ECSS-Q-ST-70-15 applies, but clause 9 is of particular relevance to fracture control and PFCI.

**ECSS-E-ST-32-01\_0810213**

- b. <<deleted (moved to ECSS-Q-ST-70-15)>>

**ECSS-E-ST-32-01\_0810214**

- c. <<deleted (moved to ECSS-Q-ST-70-15)>>

**ECSS-E-ST-32-01\_0810215**

- d. The hardware developer of composite, bonded and sandwich items shall enforce a rigorous programme to control contamination and foreign object debris (FOD) during processing.

**ECSS-E-ST-32-01\_0810216**

- e. Glass items shall be non-destructive tested and proof tested in conformance with clause 8.7.

**ECSS-E-ST-32-01\_0810217**

- f. Other non-metallic items shall be non-destructive tested and proof tested in conformance with clause 8.5.

### 10.3.3 NDT of safe life finished items

**ECSS-E-ST-32-01\_0810218**

- a. Inspection of all finished safe life items by the NDT method relevant to the assumed initial flaw size shall be performed in conformance with ECSS-Q-ST-70-15.

NOTE The complete ECSS-Q-ST-70-15 applies, but clause 9 is of particular relevance to fracture control and PFCI.

**ECSS-E-ST-32-01\_0810219**

- b. <<deleted (moved to ECSS-Q-ST-70-15)>>

**ECSS-E-ST-32-01\_0810220**

- c. <<deleted (moved to ECSS-Q-ST-70-15)>>

**ECSS-E-ST-32-01\_0810221**

- d. <<deleted (moved to ECSS-Q-ST-70-15)>>

ECSS-E-ST-32-01\_0810222

- e. <<deleted (moved to ECSS-Q-ST-70-15)>>

ECSS-E-ST-32-01\_0810223

- f. Safe life items made of glass shall be non-destructive tested and proof tested in conformance with clause 8.7.

ECSS-E-ST-32-01\_0810224

- g. Safe life items made of other non-metallic materials shall be non-destructive tested and proof tested in conformance with clause 8.5.

ECSS-E-ST-32-01\_0810225

- h. <<deleted>>

ECSS-E-ST-32-01\_0810226

- i. Except for glass items, visual testing shall not be the only NDT.

## 10.4 Non-destructive testing of metallic materials

### 10.4.1 <<deleted>>

ECSS-E-ST-32-01\_0810227

- a. <<deleted (moved to ECSS-Q-ST-70-15)>>

ECSS-E-ST-32-01\_0810228

- b. <<deleted (moved to ECSS-Q-ST-70-15)>>

### 10.4.2 NDT categories versus initial crack size

#### 10.4.2.1 <<deleted>>

ECSS-E-ST-32-01\_0810229

- a. <<deleted (moved to ECSS-Q-ST-70-15)>>

ECSS-E-ST-32-01\_0810230

- b. <<deleted (moved to ECSS-Q-ST-70-15)>>

ECSS-E-ST-32-01\_0810327

- c. <<deleted (moved to ECSS-Q-ST-70-15)>>

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**ECSS-E-ST-32-01\_0810232**

d. &lt;&lt;deleted (moved to ECSS-Q-ST-70-15)&gt;&gt;

**ECSS-E-ST-32-01\_0810233**

e. &lt;&lt;deleted (moved to ECSS-Q-ST-70-15)&gt;&gt;

**ECSS-E-ST-32-01\_0810234**

f. &lt;&lt;deleted (moved to ECSS-Q-ST-70-15)&gt;&gt;

**ECSS-E-ST-32-01\_0810235**

g. &lt;&lt;deleted (moved to ECSS-Q-ST-70-15)&gt;&gt;

**10.4.2.2 <<deleted>>**

a. &lt;&lt;deleted, modified and moved to 10.3.1n)&gt;&gt;

**ECSS-E-ST-32-01\_0810237**

b. &lt;&lt;deleted (moved to ECSS-Q-ST-70-15)&gt;&gt;

**ECSS-E-ST-32-01\_0810238**

c. &lt;&lt;deleted (moved to ECSS-Q-ST-70-15)&gt;&gt;

**ECSS-E-ST-32-01\_0810328**

d. &lt;&lt;deleted (moved to ECSS-Q-ST-70-15)&gt;&gt;

**ECSS-E-ST-32-01\_0810240**

e. &lt;&lt;deleted (moved to ECSS-Q-ST-70-15)&gt;&gt;

**10.4.2.3 Crack Screening Proof Test****ECSS-E-ST-32-01\_0810241**

a. Where proof testing of a flight item is performed as a screening or non-destructive testing technique for cracks, which are larger than the initial cracks used in the analytical life prediction, in the proof tests performed, procedures and stress analysis predictions shall ensure that the predicted stress level and distribution are actually achieved, and that the absence of test failure ensures that the cracks of the sizes to be screened out are not present in any critical location or in any orientation of the item.

**ECSS-E-ST-32-01\_0810242**

b. Where proof testing of a flight item is performed as a screening or non-destructive testing technique for cracks, which are larger than the initial cracks used in the analytical life prediction, cracks screened by proof test shall have aspect ratios identical to the initial cracks applied in the analytical life prediction.

**ECSS-E-ST-32-01\_0810243**

- c. Where proof testing of a flight item is performed as a screening or non-destructive testing technique for cracks, which are larger than the initial cracks used in the analytical life prediction, the justification of the proof test procedure shall be provided, which includes all effects that can affect the proof test definition, including as a minimum:
1. Potential of stable crack growth beyond the crack size to be screened during the proof test.
  2. Weld and parent material inhomogeneities if welds are present.
  3. Environment, if testing and operations are at different environmental conditions.

NOTE To item 1: This results in unacceptable degradation of the flight hardware.

**ECSS-E-ST-32-01\_0810244**

- d. Where proof testing of a flight item is performed as a screening or non-destructive testing technique for cracks, which are larger than the initial cracks used in the analytical life prediction, proof test procedures shall be submitted to the customer for approval prior to the start of testing.

NOTE 1 Proof testing can result in the application of loads substantially in excess of those usually imposed on flight hardware in order to screen for cracks of sufficiently small size. This can result in significant risk to damage and reject otherwise acceptable hardware.

NOTE 2 Requirements for crack growth and critical crack size analysis are specified in clause 7. A significant amount of test data can be necessary to validate or complement the analysis results in order to limit the risk of damage to flight hardware. Advanced non-linear fracture analysis methodology is normally applied to accurately predict the behaviour of cracks under proof loading, except for e.g. thick-walled items with part-through cracks where the minimum remaining ligament (material thickness ahead of crack tip) is greater than  $2,5 (K_{Ic} / \sigma_y)^2$ . A crack screening proof test of thin-walled items is generally not recommended because of the increased risk of damage due to stable crack growth during the proof test.

**Table 10-1: <<deleted (moved to ECSS-Q-ST-70-15)>>**

**10.4.3 <<deleted>>**

**10.4.3.1 <<deleted>>**

**ECSS-E-ST-32-01\_0810245**

a. <<deleted (moved to ECSS-Q-ST-70-15)>>

**ECSS-E-ST-32-01\_0810246**

b. <<deleted (moved to ECSS-Q-ST-70-15)>>

**ECSS-E-ST-32-01\_0810247**

c. <<deleted (moved to ECSS-Q-ST-70-15)>>

**10.4.3.2 <<deleted>>**

**ECSS-E-ST-32-01\_0810248**

a. <<deleted (moved to ECSS-Q-ST-70-15)>>

**ECSS-E-ST-32-01\_0810249**

b. <<deleted (moved to ECSS-Q-ST-70-15)>>

**ECSS-E-ST-32-01\_0810250**

c. <<deleted (moved to ECSS-Q-ST-70-15)>>

**ECSS-E-ST-32-01\_0810251**

d. <<deleted (moved to ECSS-Q-ST-70-15)>>

**ECSS-E-ST-32-01\_0810252**

e. <<deleted (moved to ECSS-Q-ST-70-15)>>

**10.4.3.3 <<deleted>>**

**ECSS-E-ST-32-01\_0810253**

a. <<deleted (moved to ECSS-Q-ST-70-15)>>

**ECSS-E-ST-32-01\_0810254**

b. <<deleted (moved to ECSS-Q-ST-70-15)>>



ECSS-E-ST-32-01\_0810255

c. &lt;&lt;deleted (moved to ECSS-Q-ST-70-15)&gt;&gt;

ECSS-E-ST-32-01\_0810256

d. &lt;&lt;deleted (moved to ECSS-Q-ST-70-15)&gt;&gt;

ECSS-E-ST-32-01\_0810257

e. &lt;&lt;deleted (moved to ECSS-Q-ST-70-15)&gt;&gt;

**10.4.3.4 <<deleted>>**

ECSS-E-ST-32-01\_0810258

a. &lt;&lt;deleted (moved to ECSS-Q-ST-70-15)&gt;&gt;

ECSS-E-ST-32-01\_0810259

b. &lt;&lt;deleted (moved to ECSS-Q-ST-70-15)&gt;&gt;

ECSS-E-ST-32-01\_0810329

c. &lt;&lt;deleted (moved to ECSS-Q-ST-70-15)&gt;&gt;

ECSS-E-ST-32-01\_0810261

d. &lt;&lt;deleted (moved to ECSS-Q-ST-70-15)&gt;&gt;

**10.4.3.5 <<deleted>>**

ECSS-E-ST-32-01\_0810262

a. &lt;&lt;deleted (moved to ECSS-Q-ST-70-15)&gt;&gt;

ECSS-E-ST-32-01\_0810263

b. &lt;&lt;deleted (moved to ECSS-Q-ST-70-15)&gt;&gt;

ECSS-E-ST-32-01\_0810264

c. &lt;&lt;deleted (moved to ECSS-Q-ST-70-15)&gt;&gt;

**Figure 10-1: <<deleted and moved to 7.2.6 as Figure 7-1>>****Figure 10-2: <<deleted and moved to 7.2.6 as Figure 7-2>>****Figure 10-3: <<deleted and moved to 7.2.6 as Figure 7-3>>**

## 10.5 <<deleted>>

### 10.5.1 <<deleted>>

- a. <<deleted (moved to ECSS-Q-ST-70-15)>> ECSS-E-ST-32-01\_0810265
- b. <<deleted (moved to ECSS-Q-ST-70-15)>> ECSS-E-ST-32-01\_0810266
- c. <<deleted (moved to ECSS-Q-ST-70-15)>> ECSS-E-ST-32-01\_0810267
- d. <<deleted (moved to ECSS-Q-ST-70-15)>> ECSS-E-ST-32-01\_0810268

### 10.5.2 <<deleted>>

#### 10.5.2.1 <<deleted>>

- a. <<deleted (moved to ECSS-Q-ST-70-15)>> ECSS-E-ST-32-01\_0810269
- b. <<deleted (moved to ECSS-Q-ST-70-15)>> ECSS-E-ST-32-01\_0810270
- c. <<deleted (moved to ECSS-Q-ST-70-15)>> ECSS-E-ST-32-01\_0810271

#### 10.5.2.2 <<deleted>>

##### 10.5.2.2.1 <<deleted>>

- a. <<deleted (moved to ECSS-Q-ST-70-15)>> ECSS-E-ST-32-01\_0810272
- b. <<deleted (moved to ECSS-Q-ST-70-15)>> ECSS-E-ST-32-01\_0810273
- c. <<deleted (moved to ECSS-Q-ST-70-15)>> ECSS-E-ST-32-01\_0810274

**ECSS-E-ST-32-01\_0810275**

- d. <<deleted (moved to ECSS-Q-ST-70-15)>>

**ECSS-E-ST-32-01\_0810276**

- e. <<deleted, modified and moved to 10.3.1o>>

10.5.2.2.2 <<deleted>>

**ECSS-E-ST-32-01\_0810277**

- a. <<deleted (covered by ECSS-Q-ST-70-15)>>

**ECSS-E-ST-32-01\_0810278**

- b. <<deleted (covered by ECSS-Q-ST-70-15)>>

**ECSS-E-ST-32-01\_0810279**

- c. <<deleted (moved to ECSS-Q-ST-70-15)>>

**ECSS-E-ST-32-01\_0810280**

- d. <<deleted (covered by ECSS-Q-ST-70-15)>>

## 10.6 Traceability

### 10.6.1 General

**ECSS-E-ST-32-01\_0810281**

- a. Traceability of PFCI and the materials they are made of shall be implemented in conformance with ECSS-Q-ST-20 to provide assurance that:
1. The material used in the manufacture of structural hardware has properties fully representative of those used in the analysis or verification tests.
  2. Structural hardware is manufactured and non-destructive tested in conformance with the specific requirements for the implementation of the fracture control programme.

### 10.6.2 Requirements

**ECSS-E-ST-32-01\_0810282**

- a. All associated drawings, manufacturing and quality control documentation shall identify that the item is a potential fracture-critical item (unless when it is a fail-safe or low-risk fracture metallic item) or a fracture critical item.

**ECSS-E-ST-32-01\_0810283**

- b. Each fracture-critical item shall be traceable by its own unique serial number.

**ECSS-E-ST-32-01\_0810284**

- c. Each fracture-critical item shall be identified as fracture-critical on its accompanying tag and data package.

**ECSS-E-ST-32-01\_0810285**

- d. For each fracture-critical item a log shall be maintained, which documents the environmental and operational aspects (including fluid exposure for pressure vessels) of all storage conditions during the life of the item.

**ECSS-E-ST-32-01\_0810286**

- e. For each fracture-critical item a log shall be maintained, which documents all loadings due to testing, assembly and operation, including pressure cycles and torquing of fasteners.

## 10.7 Detected defects

### 10.7.1 General

**ECSS-E-ST-32-01\_0810287**

- a. Safe life and fail safe items with detected defects with a size larger than the following, shall be subjected to additional verification requirements as defined in clause 10.7.2:
1. The acceptance criteria used in the manufacturing process; or
  2. 50 % of the maximum allowed initial NDT size in any dimension; or
  3. 50 % of the standard fracture control NDT size defined in Table 9-1 of ECSS-Q-ST-70-15, for metallic materials

NOTE 1 Acceptance criteria for flaws in the manufacturing process ensure that material property values are not reduced below the qualified minimum values used for design.

Detailed requirements for acceptance criteria for flaws other than crack-like defects are not within the scope of this ECSS standard.

NOTE 2 For example, definition of acceptance criteria for defects includes consideration of ultimate strength, fatigue life, leakage.

**ECSS-E-ST-32-01\_0810288**

- b. Any PFCI containing detected defects, as defined in 10.7.1a, shall not be used without approval of the customer.

NOTE 1 The first option to be considered when a defect is detected in flight hardware is to remove or repair the defect.

NOTE 2 For highly critical hardware (especially when used for manned spaceflight), more conservative verification methodology can be requested by the customer (see e.g. NASA-HDBK-5010).

**ECSS-E-ST-32-01\_0810289**

- c. Low risk fracture items shall not contain detected defects.

## 10.7.2 Acceptability verification

### 10.7.2.1 Safe life parts with a detected defect

#### 10.7.2.1.1 General

**ECSS-E-ST-32-01\_0810290**

- a. The detected defect shall be verified as crack-like defect, and a fracture mechanics analysis or test performed to verify the acceptability of this defect.

NOTE Only in the case of a well-known type of defect (e.g. pores) for which a data base of representative test data is available, an assessment without replacing the defect by a crack can be used.

**ECSS-E-ST-32-01\_0810291**

- b. The analysis or test shall be performed as follows:
1. Define the dimensions and location of the detected defect conservatively (e.g. for a surface crack the length and depth).
  2. In the case of irregular defect shapes or grouped defects, make a recharacterisation for the analytical prediction (in the case of metallic part) or for test with induced defect (for metallic or composite part).
  3. Demonstrate by analysis or test that the stresses used are conservative.

NOTE 1 To item 2: For metallic parts, flaw characterization as proposed by BS 7910 or ASME boiler and pressure vessel code Section XI, article IGA-3000 can be applied.

NOTE 2 To item 3: Improved analysis methods, which are subjected to customer approval, can be needed to achieve this.

**ECSS-E-ST-32-01\_0810292**

- c. There shall be no indication that the cause of the defect affects the validity of the material properties used in the safe life verification.

**ECSS-E-ST-32-01\_0810293**

- d. The analysis or test shall demonstrate ultimate load capability at the beginning of life.

**10.7.2.1.2 For metallic parts**

**ECSS-E-ST-32-01\_0810294**

- a. The safe life crack growth analysis shall be performed as specified in 7, with the complete load spectrum applied 6 times in sequence.

**ECSS-E-ST-32-01\_0810295**

- b. Cases where the analysis specified in 10.7.2.1.1a can be replaced by a representative fatigue test of a part containing a representative defect other than a crack shall be agreed with the customer.

NOTE This is agreed only in the case of a well-known type of defect.

**ECSS-E-ST-32-01\_0810296**

- c. The fatigue test specified in 10.7.2.1.2b shall demonstrate limit load capability after application of the complete load spectrum 6 times in sequence.

**10.7.2.1.3 For composite, bonded and sandwich parts**

**ECSS-E-ST-32-01\_0810297**

- a. The safe life verification shall be performed in conformance with clause 8.4.

**10.7.2.2 Fail safe parts with a detected defect**

**ECSS-E-ST-32-01\_0810298**

- a. The part shall meet the requirements in 6.3 for fail safe parts using the detected defect in conformance with 10.7.2.2b.

**ECSS-E-ST-32-01\_0810299**

- b. For the verification of 10.7.2.2a, the detected defect shall be assumed in the most unfavourable situation.

NOTE 1 This means the situation where the choice of the failed part places the detected defect in the most unfavourably loaded remaining part.

NOTE 2 This includes fatigue verification, considering the detected defects. Alternatively, it can be demonstrated that the structure can withstand the failure of any other part, in addition to failure of parts containing detected defects (using safety factors as specified in 6.3.3, and without considering a defect in the remaining structure).

**ECSS-E-ST-32-01\_0810300**

- c. For metallic parts the detected defect shall be verified as crack-like defect, and a fracture mechanics analysis or test be performed to verify the acceptability of this defect.

NOTE Only in the case of a well-known type of defect (e.g. pores) for which a data base of representative test data is available, an assessment without replacing the defect by a crack can be used.

**ECSS-E-ST-32-01\_0810301**

- d. For composite, bonded and sandwich parts the fatigue verification shall be based on tests of representative defects.

### **10.7.3 Improved probability of detection**

**ECSS-E-ST-32-01\_0810302**

- a. If the origin of a detected defect is not uniquely determined and eliminated, and regular occurrence of significant crack-like defects is not excluded by means of improvement of the manufacturing process, an improved NDT method approved by the customer shall be used, such that it provides a probability higher than 90% of detection with 95% confidence of unacceptable defects.

# 11

## Reduced fracture control programme

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### 11.1 Applicability

As specified in 5.1 for unmanned, single-mission, space vehicles and their payloads, and for GSE, a reduced fracture control programme (RFCP) as defined in this clause can be implemented, instead of the general fracture control programme.

### 11.2 Requirements

#### 11.2.1 General

**ECSS-E-ST-32-01\_0810303**

- a. A reduced fracture control programme shall be in conformance with all the requirements given in this standard, with the modifications specified in 11.2.2.

#### 11.2.2 Modifications

##### 11.2.2.1 Identification of PFCIs

**ECSS-E-ST-32-01\_0810330**

- a. The identification of PFCIs may be limited to the following items:
  - 1. Pressurized systems.
  - 2. Rotating machinery.
  - 3. Fasteners used in safe life applications.
  - 4. Items fabricated using welding, forging or casting and which are used at limit stress levels exceeding 25 % of the ultimate tensile strength of the material.
  - 5. Non-metallic structural items.
  - 6. Metallic structural items used in safe life applications, with limit stress levels exceeding 50% of the yield tensile strength of the material.



NOTE 1 When approved by the customer, the scope of this requirement (11.2.2.1a.6) can be reduced to single point of failure items loaded in tension with relatively small cross-section (examples: lugs, iso-static mounts, small strut or pin, GSE interface).

NOTE 2 For more information on PFCIs, see 6.1.

**ECSS-E-ST-32-01\_0810305**

- b. The identification of potential fracture-critical items shall be performed in conformance with the procedure given in Figure 6-1.

### **11.2.2.2 Documentation requirements**

**ECSS-E-ST-32-01\_0810331**

- a. The information specified in clause 6.4.2 may be consolidated into one list; separate lists need not be prepared.

### **11.2.2.3 Glass and non-metallic items other than composites, bonded and sandwich items**

**ECSS-E-ST-32-01\_0810332**

- a. The requirements of clauses 8.5 and 8.7 may be replaced by the following requirement: structural glass and other non-metallic items (other than composites, bonded and sandwich items) shall be proof-tested at 1,2 times the limit load.

NOTE It is well-known that glass and other brittle items subjected to static load can be sensitive to growth of inherent flaws (i.e. static fatigue). This effect is normally considered in the structural verification, taking into account empirical data (e.g. statistical methods, taking into account the surface roughness of the item).

### **11.2.2.4 Rotating machinery**

**ECSS-E-ST-32-01\_0810333**

- a. The requirements of clause 8.6 may be replaced by the following requirement: 'rotating machinery (wheels and gyros) shall be proof-spintested at one and one tenth (1,1) times nominal operational speed'.

NOTE In general, the limit speed test will fulfil this requirement as it will significantly exceed the nominal operational speed.

### 11.2.2.5 Safe life composite, bonded and sandwich structures

ECSS-E-ST-32-01\_0810348

- a. A proof test to at least 1,1 times the flight limit load shall be performed, in accordance with a proof test plan approved by the customer.

NOTE It is recommended that the applied proof loads do not exceed 80% of the ultimate strength, unless agreed otherwise with the customer.

ECSS-E-ST-32-01\_0810349

- b. Protection and NDT means shall be agreed between customer and supplier, to ensure absence of detrimental impact damage before launch.

ECSS-E-ST-32-01\_0810350

- c. Safe life areas that are tested below the required proof factor may be acceptable based on NDT with demonstrated acceptance limits and other means of process control, if agreed by the customer.

NOTE Agreement with the customer is in line with existing requirements of clause 8.4.

### 11.2.2.6 Metallic parts classified as PFCI according to 11.2.2.1

ECSS-E-ST-32-01\_0810351

- a. The low risk approach for metallic structural items used in safe life applications described below may be implemented replacing the requirements of 6.3.2 when the following conditions are met:
1. the item is shown to possess acceptable resistance to crack growth from potential initial crack-like defects, by demonstrating that assumed initial surface cracks of 0,63 mm depth and 1,27 mm length and corner cracks of 0,63 mm radius from holes and edges, or through-thickness cracks of 1,27 mm length do not grow to failure in less than four complete service lifetimes.
  2. the item is non-destructive tested by standard fracture control surface NDT method, according to ECSS-Q-ST-70-15, with exception of X-ray radiography, as minimum.
  3. the item is fabricated from a well-characterized metal, procured in conformance with the following aerospace standards AMS (MMPDS), ASTM, ISO, EN, DIN, WL, AIR, or BS or to an equivalent standard not listed before but to be approved by the customer.
  4. A reliable source of material data, linked to AMS, is provided by MMPDS.

5. the item is fabricated from a metal selected from Table 5-1 "Alloys with high resistance to stress-corrosion cracking" of ECSS-Q-ST-70-36.
6. the material is known not to be susceptible, based on heritage, to create defects during the manufacturing process.
7. if EDM is used, the requirements stated in paragraph 8.9 apply.
8. the item is not a pressurized hardware.

NOTE 1 to item 2: Standard fracture control NDT includes penetrant, eddy current, ultrasonic, magnetic particle methods. X-ray radiographic is used only with additional justification, per 9.2.2.1.f of ECSS-Q-ST-70-15. Verification of detected defects is performed i.a.w. 10.7.

NOTE 2 to item 6: Processes such as welding, forging, casting, additive manufacturing or quenching heat treatment are prone to create defects during manufacturing.

#### 11.2.2.7 Fasteners classified as PFCI according to 11.2.2.1

ECSS-E-ST-32-01\_0810352

- a. Metallic fasteners including titanium alloy may be used in safe life applications if the following conditions are met:
  1. the item meets requirements 8.8a, 8.8c, 8.8d, 8.8e and 8.8h.
  2. the item is shown to possess acceptable resistance to crack growth from potential initial crack-like defects, by demonstrating that assumed initial surface cracks of  $a = c = 0,63$  mm do not grow to failure in less than four complete service lifetimes (see Figure 7-3)..
  3. the item is non-destructive tested by standard fracture control surface NDT method, as minimum, without etching.
  4. the item is fabricated from a metal selected from Table 5-1 "Alloys with high resistance to stress-corrosion cracking" of ECSS-Q-ST-70-36.
  5. the item is not part of a pressurized shell of pressurized hardware.
  6. the item is not made of an alloy susceptible to sustained load cracking in the specified environments, unless specifically agreed otherwise, and titanium fasteners meet 11.2.2.7b.2 and 11.2.2.7b.3.

NOTE 1 to item 1: This means that requirements 8.8b, 8.8f, and 8.8g are replaced by the requirements from 11.2.2.7a.2 to 11.2.2.7a.6.

NOTE 2 to item 3: See ECSS-Q-ST-70-15, for example clause 9.2. Standard surface inspection can be fluorescent penetrant, ultrasonic, eddy current or magnetic particle testing.

NOTE 3 For safe life titanium fasteners the user can follow either requirement 11.2.2.7a or 11.2.2.7b.

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- b. Titanium alloy fasteners may be used in safe life applications if the following conditions are met:
1. they meet the requirements 8.8a and 8.8c, 8.8d, 8.8e, 8.8f, 8.8g, 8.8h.
  2. for sustained loading  $K$  is smaller than the lower bound threshold for sustained load cracking in accordance with clause 7.2.5e, or  $K < 0,5 K_{Ic}$  if no threshold value is available from test.
  3. customer approval is obtained.

NOTE For safe life titanium fasteners the user can follow either requirement 11.2.2.7a or 11.2.2.7b.

**11.2.2.8 NDT of fusion welded joints in pressure components, as per 10.3.1p****ECSS-E-ST-32-01\_0810354**

- a. X-ray testing of fusion welded joints post proof test may be omitted.

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- b. For surface crack NDT of fusion welded joints, only highly cyclic loaded locations showing a stress level due to external loading much higher than the pressure induced stresses, or a large number of pressure cycles causing high stresses shall be subjected to NDT before or after the proof test.

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- c. X-ray testing of fusion welded joints may also be omitted before proof test if all of the following requirements are met:
1. Material selection is limited to materials, which are known to be well weldable.
  2. It is demonstrated that welding verification:
    - (a) was performed in accordance with clause 11 of ECSS-Q-ST-70-39, including X-ray testing and destructive testing of verification samples, or
    - (b) is based on large heritage of the following: identical material, comparable thickness, and fusion depth, comparable weld method, jigs, tooling and parameters, without failure during or after proof testing, including X-ray testing of sufficient samples.
  3. If X-ray testing of the flight hardware is omitted or cannot be performed, in addition to other design and process control measures implemented to ensure robustness of the hardware, X-ray testing is required on accompanying samples, that are welded using parameters and a setup as close as possible to the flight hardware for representativeness, to demonstrate acceptance

criteria according to the weld specification, to the extent and with margin agreed with the customer.

4. A minimum proof pressure test factor of 1,5 is applied, while also fulfilling 8.2.1b.
5. If flaw growth due to cyclic or sustained loads cannot be neglected, safe life is demonstrated, where the potential crack extension is covered by the difference between critical crack size during proof test and critical crack size during operation, or it is based on a conservative envelope of credible weld defects agreed with the customer:

NOTE 1  $a_{cp} + \Delta a < a_{co}$

where:

$a_{cp}$  = critical crack size during proof test

$a_{co}$  = critical crack size during operation

$\Delta a$  = crack extension during dimensioning life

NOTE 2 Visual inspection of all flight welds is always requested by ECSS-Q-ST-70-39.

NOTE 3 to item 1: Examples for well weldable materials are:

(a) Ti-6Al-4V

(b) Ti-3Al-2.5V

(c) Ti-6Al-4V/Ti-3Al-2.5V dissimilar weld

(d) AA2219

(e) AA6XXX

(f) AA5XXX

(g) AISI type stainless steels

Examples of alloys which are fusion weldable only under precautions and with limitations are the standard AA7XXX alloys and AA2XXX aluminum lithium alloys.

NOTE 4 to item 3: A margin against the size specified in acceptance criteria that would apply to fully inspected flight welds is requested because flight hardware that is not inspected can contain worse imperfections than the inspected accompanying samples.

NOTE 5 to item 3: Examples of design and process control measures that help to ensure robustness of the hardware are tight tolerances and generous width of electron beam and laser welds as well as process control means to verify accurate weld path.

NOTE 6 to item 3: Acceptance criteria are defined for all credible defect types, like porosity (individual,

clustered), inclusions, geometrical imperfections (including incomplete fusion, if part of the weld design), and are relevant to the dimensions relevant to the transfer of load. Detailed requirements for acceptance criteria for flaws other than crack-like defects are not within the scope of this ECSS standard.

NOTE 7 to item 4: Examples of potential defects in welds porosity, inclusions, geometrical imperfections.

NOTE 8 to item 4: Requirement 8.2.1b limits the magnitude of loads other than pressure.

NOTE 9 to item 5: Sharp features, like lack of fusion, are considered as crack like, unless covered conservatively in another manner agreed with the customer.

NOTE 10 to item 5: The user is reminded that the standards like ECSS-E-ST-32 and ECSS-E-ST-32-02 require the hardware to be designed to sustain the proof loading without detrimental deformation, i.e. without large scale yielding.

NOTE 11 to item 5: The crack screening proof test approach described above will take into account the requirements and guidelines of clause 10.4.2.3 if not agreed otherwise with the customer.

NOTE 12 to item 5: Customer approval is required in 11.2.2.8c.5 for welds not screened by proof testing because it is normally desirable to avoid the situation where flaw growth due to cyclic or sustained loads cannot be neglected for welds that will not be inspected, especially in, for example welds, that contain a lack of fusion at the weld root by design which are generally considered non-structural.

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## Annex A (informative)

# The ESACRACK software package

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The ESACRACK software package is intended to be used for damage tolerance analysis of spaceflight vehicles and payloads as well as ground support equipment. The package consists of various analysis tools that enable the user to:

- Generate load and stress spectra (ESALOAD)
- Perform fracture mechanics analysis (NASGRO® module NASFLA)
- Generate stress intensity factor solutions (NASGRO® module NASBEM)
- Process crack growth material data (NASGRO® module NASMAT)
- Perform fatigue analysis (ESAFATIG).

The flight load spectra distributed with ESACRACK have been derived for payloads of the NSTS, and cannot be used for other structures without adequate verification.

The software package ESACRACK can be obtained from Mechanical Systems Department of ESA.

The data contained in the standard materials data bases provided with the NASGRO and ESAFATIG software, and the stress intensity and net section stress solutions implemented in the NASGRO software, are generally acceptable for fracture control analysis. The judgement of the applicability of these data for the actual hardware remains the responsibility of the user of the software, however.

The material data in the NASGRO database are mean or typical values, and a reduction as specified in clause 7.2.5 is therefore applied for the toughness parameters. A reduction option is implemented in older versions of the ESACRACK software.

Caution: The NASGRO software offers a number of advanced analysis options which are potentially unconservative and not allowed by this standard, or require specifically validated material data (e.g. retardation models like the strip-yield model, elastic-plastic analysis, shakedown analysis). Application of such options is normally subject to customer approval.

In some cases (e.g. for fracture analysis of detected cracks, for determination of defect acceptance criteria or proof test crack screening capability, or for crack growth prediction where the spectrum can cause acceleration of crack growth) the application of such advanced options in NASGRO or other fracture analysis software can be necessary.

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## Annex B (informative) References

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- [R1] Broek, 'The practical use of fracture mechanics', 1989, Kluwer, ISBN 90-247-3707-9.
- [R2] Berger, Blauel, Pyttel & Hodulak, 'FKM Guideline – Fracture Mechanics Proof of Strength for Engineering Components', 2nd revised edition, 2004, VDMA Verlag GmbH, ISBN 3-8163-0496-6.
- [R3] Sierakowski & Newaz, 'Damage tolerance in advanced composites', 1995, Technomic Publishing, ISBN 1-56676-261-8
- [R4] 'Aerospace Structural Metals Handbook', CINDAS/Purdue University
- [R5] Saxena 'Nonlinear Fracture Mechanics for Engineers', 1998, CRC Press, ISBN 0-8493-9496-1
- [R6] Chell, McClung, Kuhlman, Russell, Garr, Donnelly, 'Guidelines for Proof Test Analysis', 1999, NASA/CR-1999-209427
- [R7] McClung, Chell, Lee, Russell, Orient, 'Development of a Practical Methodology for Elastic-Plastic and Fully Plastic Fatigue Crack Growth', 1999, NASA/CR-1999-209428
- [R8] NASA/TM-2020/5006765 'Composite Overwrapped Pressure Vessel (COPV) Damage Tolerance Life Analysis Methodology and Test Best Practices', 2020 (+ Appendices)



## Bibliography

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ECSS-S-ST-00	ECSS system – Description, implementation and general requirements
ECSS-Q-ST-10-09	Space product assurance - Nonconformance control system
NASA-HDBK-5010	'Fracture control implementation handbook for payloads, experiments, and similar hardware', 2005, NASA
MIL-HDBK-17	Composite Materials Handbook
BS 7910	Guide on methods for assessing the acceptability of flaws in metallic structures