



BSI Standards Publication

Space engineering — Fracture control

National foreword

This British Standard is the UK implementation of EN 16603-32-01:2021. It supersedes BS EN 16603-32-01:2014, which is withdrawn.

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A list of organizations represented on this committee can be obtained on request to its committee manager.

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English version

Space engineering - Fracture control

Ingénierie spatiale - Maîtrise de la rupture

Raumfahrttechnik - Überwachung des Rissfortschritts

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**CEN-CENELEC Management Centre:
Rue de la Science 23, B-1040 Brussels**

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European Foreword

This document (EN 16603-32-01:2021) has been prepared by Technical Committee CEN/CLC/TC 5 "Space", the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by June 2022, and conflicting national standards shall be withdrawn at the latest by June 2022.

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

This document supersedes EN 16603-32-01:2014.

The main changes with respect to EN 16603-32-01:2014 are listed below:

- Implementation of change requests
- Replacement of term "non-destructive inspection (NDI)" by "non-destructive testing (NDT)" in the whole document
- Update of Scope
- Removal of information about the NASA Space Shuttle program (STS)
- Update of Normative References and Terms, definitions and abbreviated terms
- Addition of Nomenclature
- Addition of clause 8.2.7 "Pressurized components with non-hazardous LBB failure mode"
- Addition of clause 8.9 "Alloys treated with electric discharge manufacturing (EDM)"
- Addition of clause 11.2.2.5 "Safe life composite, bonded and sandwich structures"
- Addition of clause 11.2.2.6 "Metallic parts classified as PFCI according to 11.2.2.1"
- Addition of clause 11.2.2.7 "Fasteners classified as PFCI according to 11.2.2.1"
- Addition of clause 11.2.2.8 "NDT of fusion welded joints in pressure components, as per 10.3.1p"
- Several clauses and requirements moved to EN 16602-70-15 (equivalent to ECSS-Q-ST-70-15)

This document has been prepared under a standardization request given to CEN by the European Commission and the European Free Trade Association.

This document has been developed to cover specifically space systems and has therefore precedence over any EN covering the same scope but with a wider domain of applicability (e.g. : aerospace).

According to the CEN-CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

1

Scope

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

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.

EN reference	Reference in text	Title
EN 16601-00-01	ECSS-S-ST-00-01	ECSS system – Glossary of terms
EN 16603-10-02	ECSS-E-ST-10-02	Space engineering – Verification
EN 16603-10-03	ECSS-E-ST-10-03	Space engineering - Testing
EN 16603-32	ECSS-E-ST-32	Space engineering – Structural general requirements
EN 16603-32-02	ECSS-E-ST-32-02	Space engineering – Structural design and verification of pressurized hardware
EN 16602-20	ECSS-Q-ST-20	Space product assurance – Quality assurance
EN 16602-40	ECSS-Q-ST-40	Space product assurance – Safety
EN 16602-70	ECSS-Q-ST-70	Space product assurance – Materials, mechanical parts and processes
EN 16602-70-15	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

Terms, definitions and abbreviated terms

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 (kg.m^2) and ω is the angular velocity (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, ΔK_{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

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

Abbreviation	Meaning
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.

4 Principles

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

Fracture control programme

5.1 General

- 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.

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

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

- 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.

- 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

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

- 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

- 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.

- 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.

Identification and evaluation of PFCI

6.1 Identification of PFCIs

- 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.

- 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.
- 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

- 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.

- e. <<deleted>>
- 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.

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