

BS EN 16603-32-01:2014



BSI Standards Publication

Space engineering — Fracture control

bsi.

...making excellence a habit.
AVA Documents™
Document Sharing Hub

National foreword

This British Standard is the UK implementation of EN 16603-32-01:2014. It supersedes BS EN 14165:2004 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee ACE/68, Space systems and operations.

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

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

© The British Standards Institution 2014. Published by BSI Standards Limited 2014

ISBN 978 0 580 83980 1

ICS 49.140

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 August 2014.

Amendments issued since publication

Date	Text affected
------	---------------

English version

Space engineering - Fracture control

Ingénierie spatiale - Maîtrise de la rupture

Raumfahrttechnik - Überwachung des Rissfortschritts

This European Standard was approved by CEN on 10 February 2014.

CEN and CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN-CENELEC Management Centre or to any CEN and CENELEC member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN and CENELEC member into its own language and notified to the CEN-CENELEC Management Centre has the same status as the official versions.

CEN and CENELEC members are the national standards bodies and national electrotechnical committees of 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, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and United Kingdom.



**CEN-CENELEC Management Centre:
Avenue Marnix 17, B-1000 Brussels**

Table of contents

Foreword	6
1 Scope.....	7
2 Normative references	8
3 Terms, definitions and abbreviated terms.....	10
3.1 Terms from other standards.....	10
3.2 Terms specific to the present standard	11
3.3 Abbreviated terms.....	17
4 Principles	19
5 Fracture control programme	21
5.1 General.....	21
5.2 Fracture control plan.....	21
5.3 Reviews	22
5.3.1 General	22
5.3.2 Safety and project reviews	23
6 Identification and evaluation of PFCI.....	25
6.1 Identification of PFCIs.....	25
6.2 Evaluation of PFCIs	26
6.2.1 Damage tolerance.....	26
6.2.2 Fracture critical item classification	28
6.3 Compliance procedures	28
6.3.1 General	28
6.3.2 Safe life items	28
6.3.3 Fail-safe items.....	29
6.3.4 Contained items	30
6.3.5 Low-risk fracture items	31
6.4 Documentation requirements	36
6.4.1 Fracture control plan	36
6.4.2 Lists	36
6.4.3 Analysis and test documents.....	36

6.4.4	Fracture control summary report	36
7	Fracture mechanics analysis.....	38
7.1	General.....	38
7.2	Analytical life prediction	39
7.2.1	Identification of all load events	39
7.2.2	Identification of the most critical location and orientation of the crack.....	39
7.2.3	Derivation of stresses for the critical location.....	40
7.2.4	Derivation of the stress spectrum	40
7.2.5	Derivation of material data	41
7.2.6	Identification of the initial crack size and shape.....	41
7.2.7	Identification of an applicable stress intensity factor solution.....	42
7.2.8	Performance of crack growth calculations	43
7.3	Critical crack-size calculation	43
8	Special requirements	45
8.1	Introduction.....	45
8.2	Pressurized hardware	45
8.2.1	General	45
8.2.2	Pressure vessels.....	45
8.2.3	Pressurized structures	48
8.2.4	Pressure components	48
8.2.5	Low risk sealed containers.....	49
8.2.6	Hazardous fluid containers.....	49
8.3	Welds	50
8.3.1	Nomenclature.....	50
8.3.2	Safe life analysis of welds	50
8.4	Composite, bonded and sandwich structures.....	51
8.4.1	General	51
8.4.2	Defect assessment.....	51
8.4.3	Damage threat assessment	53
8.4.4	Compliance procedures	54
8.5	Non-metallic items other than composite, bonded, sandwich and glass items	57
8.6	Rotating machinery.....	58
8.7	Glass components	58
8.8	Fasteners	59
9	Material selection	61
10	Quality assurance and Inspection	62

10.1 Overview	62
10.2 Nonconformances.....	62
10.3 Inspection of PFCI	62
10.3.1 General	62
10.3.2 Inspection of raw material	63
10.3.3 Inspection of safe life finished items	64
10.4 Non-destructive inspection of metallic materials	65
10.4.1 General	65
10.4.2 NDI categories versus initial crack size	65
10.4.3 Inspection procedure requirements for standard NDI	69
10.5 NDI for composites, bonded and sandwich parts	72
10.5.1 General	72
10.5.2 Inspection requirements	73
10.6 Traceability	74
10.6.1 General	74
10.6.2 Requirements.....	75
10.7 Detected defects.....	75
10.7.1 General	75
10.7.2 Acceptability verification	76
10.7.3 Improved probability of detection.....	77
11 Reduced fracture control programme	78
11.1 Applicability.....	78
11.2 Requirements	78
11.2.1 General	78
11.2.2 Modifications	78
Annex A (informative) The ESACRACK software package.....	80
Annex B (informative) References	81
Bibliography.....	82
 Figures	
Figure 5-1: Identification of PFCI	22
Figure 6-1: Fracture control evaluation procedures	27
Figure 6-2: Safe life item evaluation procedure for metallic materials	33
Figure 6-3: Safe life item evaluation procedure for composite, bonded and sandwich items	34
Figure 6-4: Evaluation procedure for fail-safe items.....	35

Figure 8-1: Procedure for metallic pressure vessel and metallic liner evaluation 47

Figure 10-1: Initial crack geometries for parts without holes 71

Figure 10-2: Initial crack geometries for parts with holes 72

Figure 10-3: Initial crack geometries for cylindrical parts 72

Tables

Table 8-1: Factor on stress for sustained crack growth analysis of glass items 59

Table 10-1: Initial crack size summary, standard NDI 68

Foreword

This document (EN 16603-32-01:2014) has been prepared by Technical Committee CEN/CLC/TC 5 “Space”, the secretariat of which is held by DIN.

This standard (EN 16603-32-01:2014) originates from ECSS-E-ST-32-01C Rev. 1.

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 February 2015, and conflicting national standards shall be withdrawn at the latest by February 2015.

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 14165:2004.

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, 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 when required by ECSS-Q-ST-40 or by the NASA document NST 1700.7, incl. ISS addendum.

The requirements contained in this Standard, when implemented, also satisfy the fracture control requirements applicable to the NASA STS and ISS as specified in the NASA document NSTS 1700.7 (incl. the ISS Addendum).

The NASA nomenclature differs in some cases from that used by ECSS. When STS/ISS-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.

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 16603-32	ECSS-E-ST-32	Space engineering – Structural
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 16602-70-36	ECSS-Q-ST-70-36	Space product assurance – Material selection for controlling stress-corrosion cracking
EN 16602-70-45	ECSS-Q-ST-70-45	Space product assurance – Mechanical testing of metallic materials
	ASTM E 164	Standard Practice for Ultrasonic Contact Examination of Weldments
	ASTM E 426	Standard Practice for Electromagnetic (Eddy-Current) Examination of Seamless and Welded Tubular Products, Austenitic Stainless Steel and Similar Alloys
	ASTM E 1417	Standard Practice for Liquid Penetrant Examination
	ASTM E 1444	Standard Practice for Magnetic Particle Examination
	ASTM E 1742	Standard Practice for Radiographic Examination
	DOT/FAA/AR-MMPDS	Metallic Materials Properties Development and Standardization (MMPDS) (former MIL-HDBK-5)
	EN 4179	Aerospace – Qualification and Authorization of Personnel for Non-destructive Testing

EN reference	Reference in text	Title
	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
	MIL-HDBK-6870	Inspection program requirements, nondestructive, for aircraft and missile materials and parts
	NAS-410	Nondestructive testing personnel qualification and certification
	NSTS 1700.7	Safety Policy and Requirements For Payloads Using the Space Transportation System (STS)
	NSTS 1700.7 ISS Addendum	Safety Policy and Requirements For Payloads Using the International Space Station
	SAE AMS-STD-2154	Process for inspection, ultrasonic, wrought metals
	SAE AMS 2644	Inspection Material, Penetrant
	NSTS/ISS 13830	Payload Safety Review and Data Submittal Requirements For Payloads Using the Space Shuttle & International Space Station

Terms, definitions and abbreviated terms

3.1 Terms from other standards

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

customer

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

For the purpose of this Standard, the following term and definition from ECSS-E-ST-10-03 apply:

proof test

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

flaw

NOTE The term defect is used as a synonymous.

maximum design pressure (MDP)

service life

For the purpose of this Standard, the following term and definition from ECSS-E-ST-32-02 apply:

burst pressure

hazardous fluid container

leak before burst, LBB

pressure component

pressure vessel

pressurized structure

sealed container

special pressurized equipment

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 inspection.

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.

For the purpose of this Standard, the following term and definition from ECSS-Q-ST-40 apply:

catastrophic hazard

critical hazard

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 catastrophic hazard

<other than NASA STS or ISS payloads> see ECSS-Q-ST-40B

3.2.4 catastrophic hazard

<NASA STS or ISS payloads> potential risk situation that can result in a disabling or fatal personnel injury, loss of the NASA orbiter, ISS, ground facilities, or STS/ISS equipment

[NSTS 1700.7 incl. ISS Addendum, paragraph 302]

3.2.5 close visual inspection

close proximity, intense visual examination of the internal and external surfaces of a structure, including structural details or locations, for indications of impact damage, flaws, and other surface defects

NOTE The inspection capability is evaluated by the surface deflection measurement (impact depth). The close visual inspection is considered to

detect reliably a deflection larger than the visual damage threshold (VDT).

3.2.6 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.

3.2.7 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.

3.2.8 crack aspect ratio, a/c

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

3.2.9 crack aspect ratio, a/c

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

3.2.10 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 .

3.2.11 crack growth retardation

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

3.2.12 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)

3.2.13 critical initial defect, CID

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

3.2.14 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 . 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 3.2.25.

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

3.2.15 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.

3.2.16 damage tolerance threshold strain

<composite structural items> maximum strain level below which damage compatible with the sizes established by non-destructive inspection (NDI), special visual inspection, 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).

3.2.17 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

3.2.18 defect

see 'flaw' (3.1)

3.2.19 detected defect

defect known to exist in the hardware

3.2.20 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

3.2.21 fastener

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

3.2.22 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

3.2.23 fracture critical item

item classified as such

3.2.24 fracture limited life item

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

3.2.25 fracture toughness

materials' resistance to the unstable propagation of a crack

NOTE See critical stress intensity factor, 3.2.14.

3.2.26 initial crack size

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

3.2.27 joint

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

3.2.28 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.

3.2.29 loading event

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

3.2.30 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.

3.2.31 mechanical damage

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

3.2.32 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 or critical hazard, or NASA STS/ISS catastrophic hazardous consequences

NOTE Pressure vessels and rotating machinery are always considered PFCI. See Figure 5-1.

3.2.33 R-ratio

ratio of the minimum stress to maximum stress

3.2.34 residual stress

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

3.2.35 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).

3.2.36 safe life

fracture-control design principle, for which the largest undetected defect that can exist in the part does not grow to failure when subjected to the cyclic and sustained loads and environments encountered in the service life

3.2.37 special NDI

NDI methods that are capable of detecting cracks or crack-like flaws smaller than those assumed detectable by Standard NDI or do not conform to the requirements for Standard NDI

NOTE 1 See 10.4.2.1 and 10.4.3.

NOTE 2 Special NDI methods are not limited to fluorescent penetrant, radiography, ultrasonic, eddy current, and magnetic particle. See also 10.4.2.2.

3.2.38 standard NDI

NDI methods of metallic materials for which the required statistically based flaw detection capability has been established. and it is listed in Table 10-1

NOTE 1 For standard NDI, see clauses 10.4.2.1 and 10.4.3.

NOTE 2 For required statistically based flaw detection capability, see 10.4.2.1e.

NOTE 2 Limitations on the applicability of standard NDI to radiographic NDI can be found in 10.4.2.1f and 10.4.2.1g.

NOTE 4 Standard NDI methods addressed by this document are limited to fluorescent penetrant, radiography, ultrasonic, eddy current, and magnetic particle.

3.2.39 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} .

3.2.40 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 3.2.14.

3.2.41 threshold stress intensity range, ΔK_{th}

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

3.2.42 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 3.2.8)
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
EN	European Standard
EPFM	elastic-plastic fracture mechanics
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 3.2.14.
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
NDI	non-destructive inspection
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
SCC	stress-corrosion cracking
SI	international system of units
SRR	system requirements review
STS	Space Transportation System (US Space Shuttle)
US	ultrasonic
VDT	visual damage threshold

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 inspection (NDI) 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 (NDI, 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 NSTS and ISS payloads, entities controlling the pressure are two-fault tolerant, see NSTS 1700.7 (incl. ISS Addendum).

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

5

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, when required by ECSS-Q-ST-40 or the NASA document NSTS 1700.7, incl. ISS Addendum (clause 208.1).
- b. Fracture control requirements as defined in this standard shall be applied where structural failure can result in a catastrophic or critical hazard.

NOTE In NASA NSTS 1700.7 (Safety Policy and Requirements For Payloads Using the Space Transportation System [STS]), incl. ISS Addendum, the payload structural design is based on fracture control procedures when the failure of a structural item can result in a catastrophic event.

- 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. Items for which implementation of fracture control programme is required shall be selected in conformance with Figure 5-1.
- e. For unmanned, single-mission, space vehicles and their payloads, and GSE the reduced fracture control programme, specified in clause 11, may be implemented.

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.

Legend

* contained or restrained items (see subclause 6.3.4) are generally not considered PFCI. Their containers are.

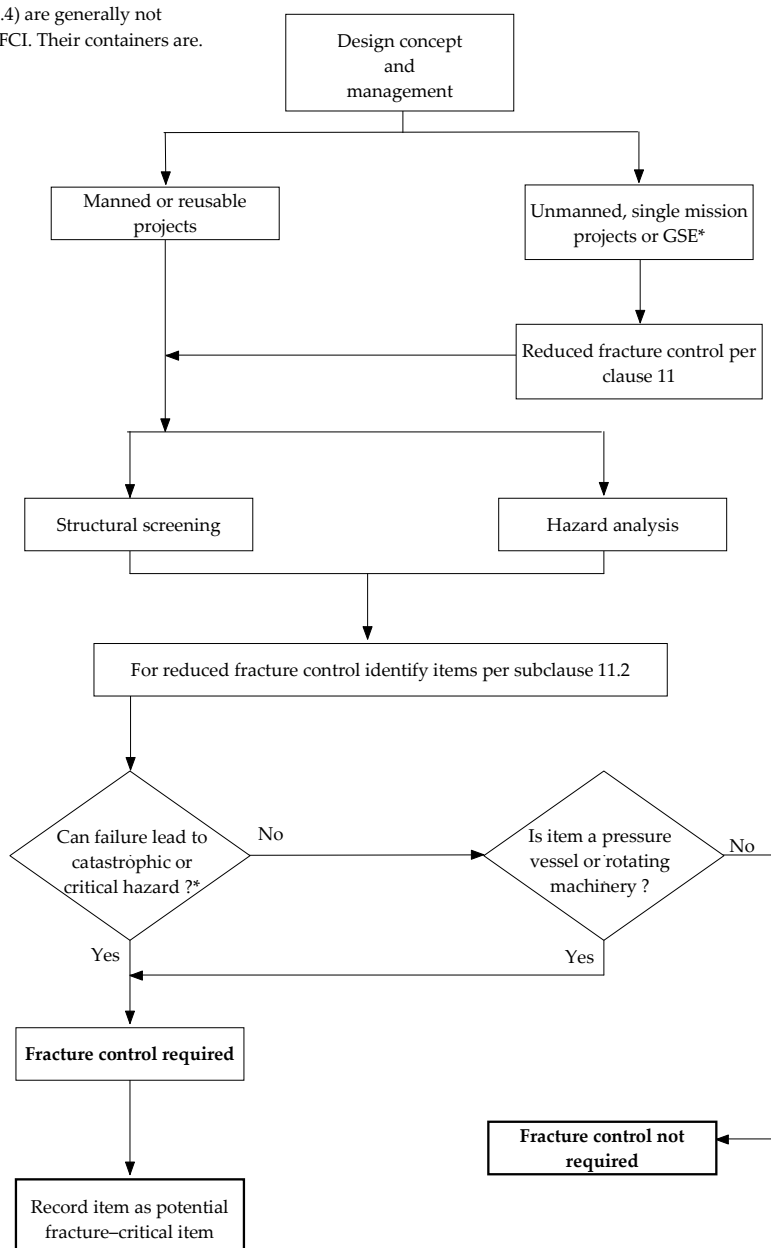


Figure 5-1: Identification of PFCI

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 5-1) 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:

- Definition of the scope of planned fracture control activities dependent upon the results of the hazard-analysis and fracture control screening performed.
- Identification of low-risk fracture items.
- Identification of primary design requirements and constraints which are affected by or affecting fracture control implementation.

NOTE For the fracture control plan, see 5.2.

(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 inspection 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.

NOTE See clause 6.4.

- (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, inspection, 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, and, for payloads of the NSTS and ISS, in conformance with NSTS/ISS 13830 clauses 7.2 and 7.12.