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FOR SPACE STANDARDIZATION

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Fracture control

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Foreword

This Standard is one of the series of ECSS Standards intended to be applied together for the management, engineering and product assurance 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 standards.

The formulation of this Standard takes into account the existing ISO 9000 family of documents.

This ECSS level 3 Engineering Standard specifies the fracture control requirements to be imposed in space programmes.

The Standard has been prepared by editing ESA PSS-01-401, reviewed by the ECSS Technical Panel, and approved by the ECSS Steering Board.

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Scope

This Standard specifies the fracture control requirements to be imposed on space systems.

The requirements contained in this Standard, when implemented, also satisfy the requirements applicable to the NASA STS and ISS as defined in the NASA document NSTS 1700.7 (incl. the ISS Addendum). Since this Standard and the NASA document NSTS 1700.7 (incl. the ISS Addendum) are subject to different independent approval authorities, and recognizing that possible changes to documents may occur in the future, the user of this Standard is advised to confirm the current status.

The definitions used in this Standard are based on ECSS nomenclature and are given in clause 3. The NASA nomenclature differs in some cases from that used by ECSS. When STS-specific requirements and nomenclature are included, they are identified as such.

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2 Normative references

This ECSS Standard incorporates, by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these apply to this ECSS Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies.

ECSS-P-001	Glossary of terms
ECSS-Q-20	Space product assurance – Quality assurance
ECSS-Q-20-09	Space product assurance – Nonconformance control system
ECSS-Q-40	Space product assurance – Safety
ECSS-Q-70	Space product assurance – Materials, mechanical parts and processes
ECSS-Q-70-36	Space product assurance – Material selection for controlling stress-corrosion cracking
MSFC-STD-1249	Standard NDE guidelines and requirements for fracture control programs
MIL-STD-1522A	Standard general requirement for safe design and operation of pressurized missile and space systems
MIL-I-6870	Inspection program requirements, nondestructive, for aircraft and missile materials and parts
MIL-STD-410	Nondestructive testing personnel qualification and certification
NSTS 13830	Implementation Procedure for NSTS Payload System Safety Requirements
NSTS 1700.7	Safety Policy and Requirements For Payloads Using the Space Transportation System (STS)
ISS Addendum	For Payloads Using the International Space Station

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3

Terms, definitions and abbreviated terms

3.1 Terms and definitions

The following terms and definitions are specific to this Standard in the sense that they are complementary or additional with respect to those contained in ECSS-P-001 and ECSS-Q-70.

3.1.1 Aggressive environment

Any 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.

3.1.2 Allowable load

The load that induces the allowable stress in a material.

3.1.3 Allowable stress

The maximum stress that can be permitted in a material for a given operating environment to prevent rupture, collapse, detrimental deformation or unacceptable crack growth.

3.1.4 Analytical life

Life evaluated analytically, i.e. by crack-growth analysis or fatigue analysis.

3.1.5 Burst pressure

The pressure at which a pressurized system ruptures or collapses.

3.1.6 Catastrophic hazard

A potential risk situation that can result in loss of life, in life-threatening or permanently disabling injury, in occupational illness, loss of an element of an interfacing manned flight system, loss of launch site facilities or long term detrimental environmental effects.

NOTE For payloads of the NASA STS or ISS, the applicable definition is:
A potential risk situation that can result in personnel injury, loss of the NASA orbiter, ground facilities, or STS equipment (see NSTS 1700.7, paragraph 302).

3.1.7 Containment

A technique that, if a part fails, prevents the propagation of failure effects beyond the container boundaries.

3.1.8 Crack or crack-like defect

A defect that behaves like a crack that isinitiated, for example, during material production, fabrication or testing or developped during the service life of a component.

NOTE The term “crack” in this definition includes flaws, inclusions, pores and other similar defects.

3.1.9 Crack aspect ratio

For a part-through crack, the ratio of crack depth (a) to half crack length (c), i.e. a/c.

3.1.10 Crack growth rate (*da/dN, dc/dN, da/dt or dc/dt*)

The rate of change of depth a or length c with respect to the number of load cycles N or time t.

3.1.11 Crack growth retardation

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

3.1.12 Critical hazard

A potential risk situation that can result in:

- temporarily disabling but not life-threatening injury, or temporary occupational illness;
- loss of, or major damage to, flight systems, major flight system elements or ground facilities;
- loss of, or major damage to, public or private property; or short-term detrimental environmental effects.

3.1.13 Critical stress-intensity factor (Fracture toughness)

The value of the stress-intensity factor at the tip of a crack at which unstable propagation of the crack occurs. 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 3.1.38.

3.1.14 Cyclic loading

A fluctuating load (or pressure) characterized by relative degrees of loading and unloading of a structure. Examples are loads due to transient responses, vibro-acoustic excitation, flutter and oscillating or reciprocating mechanical equipment.

3.1.15 Damage tolerant

A structure is considered to be damage tolerant if the amount of general degradation and/or the size and distribution of local defects expected during operation do not lead to structural degradation below limit-specified performance.

3.1.16 Fail-safe (structure)

A damage-tolerance acceptability category in which the structure is designed with sufficient redundancy to ensure that the failure of one structural element does not cause general failure of the entire structure.

3.1.17 Failure (structural)

The rupture, collapse, seizure, excessive wear or any other phenomenon resulting in an inability to sustain limit loads, pressures and environments.

3.1.18 Fastener

Any item that joins other structural items and transfers loads from one to the other across a joint. See 3.1.23.

3.1.19 Fatigue

In materials and structures, the cumulative irreversible damage incurred by cyclic application of loads in given environments. Fatigue can initiate and extend cracks, which degrade the strength of materials and structures.

3.1.20 Fracture limited life item

Any item that requires periodic reinspection to comply with safe life (see 3.1.34) or fail-safe (see 3.1.16) requirements.

3.1.21 Fracture toughness

See 3.1.13.

3.1.22 Initial crack size

The maximum crack size, as defined by non-destructive inspection, that is assumed to exist for the purpose of performing a fracture mechanics evaluation.

3.1.23 Joint

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

3.1.24 Leak before burst

Fracture mechanics design concept in which it is shown that any initial defect grows through the wall of a pressurized system and cause leakage prior to burst (catastrophic failure) at maximum design pressure (MDP). See 3.1.28

3.1.25 Limit load or stress

The maximum load or stress assumed to act on a structure in the expected operating environments.

3.1.26 Loading event

A condition, phenomenon, environment or mission phase to which the payload is exposed and which induces loads in the payload structure.

3.1.27 Load spectrum (history)

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

3.1.28 Maximum design pressure (MDP)

For a pressurized system, maximum design pressure is the highest possible pressure occurring from maximum relief pressure, maximum regulator pressure, maximum temperature or transient pressure excursions. Factors of safety apply to MDP.

3.1.29 Payload

Any equipment or material carried by the launcher that is not considered part of the basic launcher itself. It therefore includes items such as free-flying automated spacecraft, individual experiments and instruments.

3.1.30 Proof test

The test of a flight structure at a proof load or pressure that gives evidence of satisfactory workmanship and material quality or establishes the initial crack sizes in the structure.

3.1.31 R

The ratio of the minimum stress to maximum stress.

3.1.32 Residual stress

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

3.1.33 Rotating machinery

Any rotating mechanical assembly that has a kinetic energy of 19 300 joules or more, the amount being 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).

3.1.34 Safe life

A fracture-control acceptability category which requires that the largest undetected crack that can exist in the part will not grow to failure when subjected to the cyclic and sustained loads and environments encountered in the service life.

3.1.35 Service life

The interval beginning with an item's inspection after manufacture and ending with completion of its specified life.

3.1.36 Static load (stress)

A load (stress) of constant magnitude and direction with respect to the structure.

3.1.37 Stress-Corrosion Cracking (SCC)

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

3.1.38 Stress intensity factor (K)

A calculated quantity that is used in fracture mechanics analyses as a measure of the stress-field intensity near the tip of an idealised crack. Calculated for a specific crack size, applied stress level and part geometry. See 3.1.13.

3.1.39 Thermal load (stress)

The structural load (or stress) arising from temperature gradients and differential thermal expansion between structural elements, assemblies, subassemblies or items.

3.1.40 Ultimate strength

The strength corresponding to the maximum load or stress that an unflawed structure or material can withstand without incurring rupture or collapse.

3.1.41 Variable amplitude spectrum

A load spectrum or history whose amplitude varies with time.

3.1.42 Yield strength

The strength corresponding to the maximum load or stress that an unflawed structure or material can withstand without incurring permanent deformation.

3.2 Abbreviated terms

The following abbreviated terms are defined and used within this Standard.

Abbreviation	Meaning
AR	Acceptance Review
ASME	American Society of Mechanical Engineers
CDR	Critical Design Review
DOT	United States Department of Transportation
DRD	Document Requirements Definition
EFCB	ESA Fracture Control Board
ESA	European Space Agency
FCI	Fracture-critical Item
FCIL	Fracture-critical Item List
FLLI	Fracture-limited Life Item

FLLIL	Fracture-limited Life Items List
GSE	Ground Support Equipment
ISS	International Space Station
LBB	Leak Before Burst
K_{IC}	Plane strain fracture toughness. See Critical stress intensity factor
K_{ISCC}	Threshold stress-intensity factor for stress-corrosion cracking. 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
K_{th}	Threshold stress-intensity factor for dynamic loading. The stress-intensity range below which crack growth will not occur under cyclic loading
MDP	Maximum Design Pressure
MEOP	Maximum Expected Operating Pressure
NASA	National Aeronautics and Space Administration
NDI	Non-destructive Inspection
NDE	Non-destructive Evaluation
NSTS	The National Space Transportation System (NASA Space Shuttle)
PDR	Preliminary Design Review
PFCI	Potential Fracture-critical Item
PFCIL	Potential Fracture-critical Item List
R	The ratio of the minimum stress to maximum stress
RFCP	Reduced Fracture-control Programme
SCC	Stress-Corrosion Cracking
SI	The international system of units published by the International Standards Organisation
SRR	System Requirements Review
STS	Space Transportation System (US Space Shuttle)

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4

General requirements

Fracture control principles shall be applied where structural failure can result in a catastrophic or critical hazard. The terms “catastrophic hazard” and “critical hazard” are defined in subclause 3.1 of this Standard.

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

For the implementation of the ECSS-E-30-01 standard the SI-units and associated symbols system shall be used.

The assumptions and prerequisites which are the basis of the requirements contained in this standard are the following:

a. All real 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.

b. After undergoing a sufficient number of cycles at a sufficiently high stress amplitude, materials exhibit a tendency to initiate fatigue cracks, even in non-aggressive environments.

c. Whether, under cyclic and/or sustained tensile stress, a pre-existing (or load-induced) crack does or does not propagate depends on:
   - the fracture toughness of the material;
   - 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 temperature of the material.

d. The engineering discipline of linear elastic fracture mechanics provides analytical tools for the prediction of crack propagation and critical crack size.

e. For non-metallic materials (other than glass and glass-like 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. Fracture control of these materials relies on the techniques of containment, fail safe assessment, proof testing and cyclic load testing.

f. A scatter factor is required to account for the observed scatter in measured material properties and fracture mechanics analysis uncertainties.

g. For NSTS and ISS payloads, entities like regulators, relief devices and thermal control systems controlling the pressure, shall be two-fault tolerant, see NSTS 1700.7.

5 Fracture control programme

5.1 General

a. A fracture control programme shall be implemented for space systems and their related GSE in accordance with the standard of this specification, when required by ECSS-Q-40A or the NASA document NSTS 1700.7, incl. ISS Addendum.

A fracture control programme shall require that design be based on fracture control principles and procedures when the initiation or propagation of cracks in structural items during the service life can result in a catastrophic or critical hazard, or NASA STS catastrophic hazardous consequences, or when the structural item is a pressure vessel or is rotating machinery (see Figure 1).

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

5.2 Responsibilities of supplier

The equipment supplier shall be responsible for the implementation of the fracture control programme required by this standard.

5.3 Fracture control plan

a. The supplier shall prepare and implement a fracture control plan which complies with the requirements of this standard. The fracture control plan, which shall be subject to approval by the customer, shall define the fracture control programme that shall be implemented and shall show how the supplier performs and verifies the satisfactory completion of each of the activities in the fracture control programme.

b. In the fracture control plan, each fracture control activity shall be identified and defined, the method of implementation summarised, and the implementation schedule specified against project milestones. All applicable requirements and procedures shall be identified.

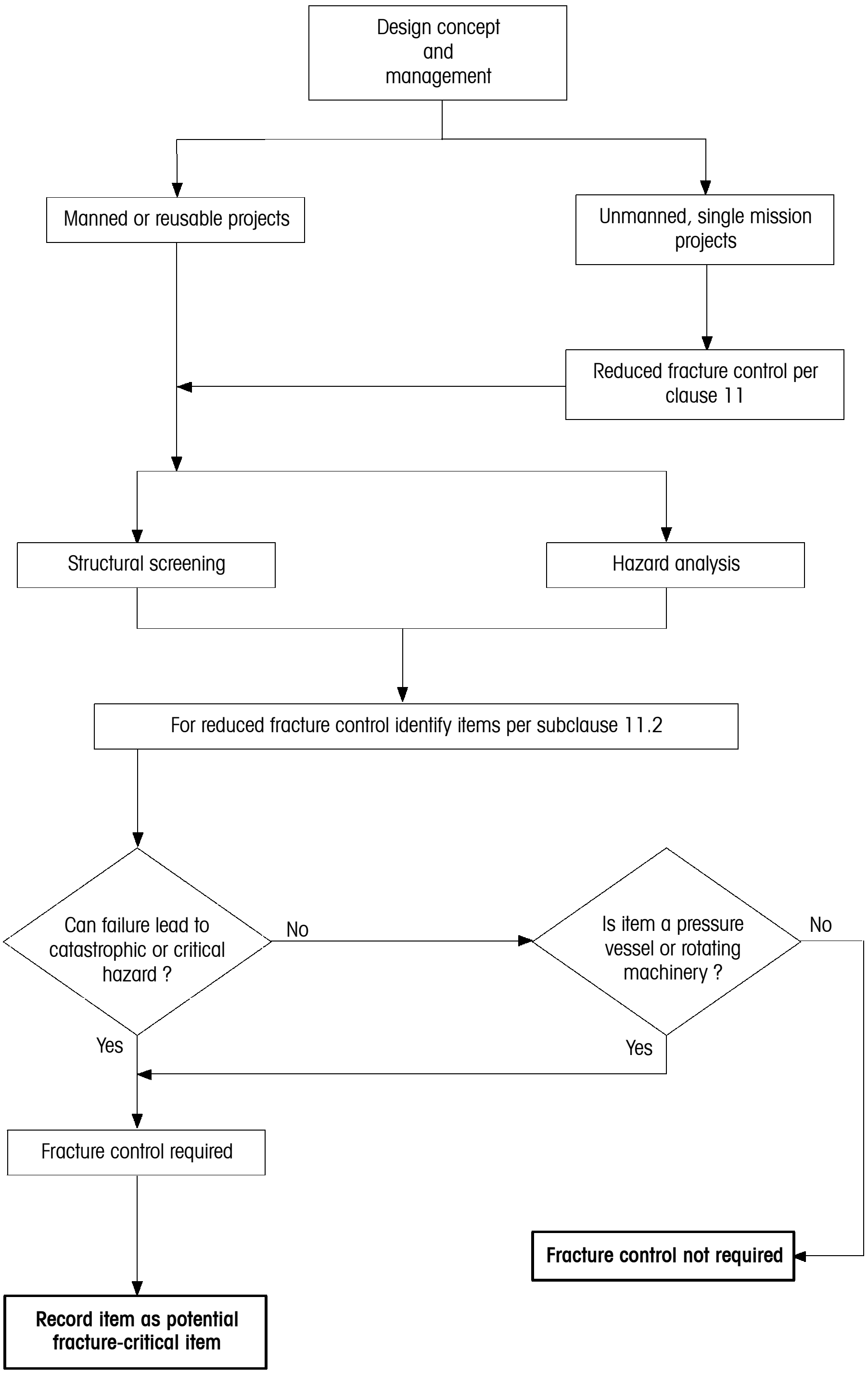

Figure 1: Fracture control applicability

5.4 Reviews

5.4.1 General

Fracture control activities and status shall be addressed during all project reviews.

5.4.2 Safety Reviews

a. The schedule of fracture control activities shall be related to, and shall support, the project safety review schedule. Safety reviews shall be performed in parallel with major programme reviews as required by ECSS-Q-40.

b. Fracture control documentation shall be provided for the safety reviews as defined below:

1. *For a System Requirements Review (SRR)*
The results of preliminary hazard analysis and fracture control screening (which follows the methodology given in Figure 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 initial fracture control-related project activities, including:

- scope of planned fracture control activities dependent upon the results of the hazard-analysis and fracture control screening performed;
- definition and outline of the fracture control plan;
- identification of primary design requirements/constraints.

(c) list of potential fracture critical items.

3. *For a Critical Design Review (CDR)*

(a) a fracture control plan which has been 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 (see subclause 6.4);

(e) list of potential fracture critical items.

4. *For an Acceptance Review (AR)*

(a) a status report showing completion of all fracture control verification activities;

(b) relevant test, inspection and analysis reports;

(c) list of potential fracture critical items in accordance with subclause 6.4.1 a.;

(d) list of fracture critical items in accordance with subclause 6.4.1 b.;

(e) list of fracture limited-life items in accordance with subclause 6.4.1 c.;

(f) pressure-vessel summary log (for payloads of the NSTS, see NSTS 13830).

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6

Identification and evaluation of PFCIs

6.1 Identification of PFCIs

a. Fracture control screening shall be performed for the complete structure, including related GSE directly connected to the flight structure unless clause 11 applies, the aim being to identify potential fracture-critical items (PFCI) which shall be included in the potential fracture-critical item list (PFCIL), defined in subclause 6.4 (see also Figure 1).

The structural screening shall be performed in a systematic way and shall be documented in a clear, concise and complete manner.

b. Hazard analysis of the space system shall be performed as required by ECSS-Q-40. This analysis shall identify the hazards and hazardous conditions which can be created by the design of a space system and its operation, possible hazardous events and their causes, and the means by which the hazards can be eliminated or minimized and controlled.

c. Hazard analysis and structural screening shall be repeated, as necessary, in an iterative manner that takes design progress and design changes into account, in order to ensure that implementation of the fracture control plan is compatible with the current design and service-life scenario.

6.2 Evaluation of PFCIs

6.2.1 General

a. PFCIs shall typically be divided into:

1. pressurized systems;
2. composites;
3. weldings and castings;
4. rotating machinery;
5. other items of which the structure is comprised.

b. Each PFCI shall be damage tolerant. For the evaluation the “safe life” logic or the “fail-safe” logic shall be used, depending on the design principle used, as shown in Figure 2. In addition, the special requirements defined in clause 8 shall be implemented.

c. For payloads on the NSTS or ISS, the following additional criteria for selection of PFCIs shall be applied. Where failure of the item would:

1. result in the release of any element or fragment with a mass of more than 113,5 g; or
2. result in the release or separation of any tension preloaded structural element or fragment with a mass of more than 13 g if the item has a fracture toughness (K_{IC}) to tensile yield strength ratio less than 1,66 $mm^{1/2}$, or if the item is a steel bolt whose ultimate strength exceeds 1240 MPa (180 ksi); or
3. result in the release of hazardous substances; or
4. prevent configuration for safe descent from orbit;
5. release on separation during zero gravity flight of any mass that can impact critical hardware or crew personnel, with a velocity higer than 10,7 m/s or a momentum exceeding 1,21 Ns;

then that item shall be classed as a PFCI.

6.2.2 Selection of the relevant locations on a PFCI

The most critical locations on a PFCI shall be identified, to enable fracture analysis to be performed. The following parameters shall be considered as criteria for the selection of PFCIs:

a. the maximum level of local stress;
b. the range of cycling stress;
c. locations to be analysed showing high stress intensities (correction function);
d. areas where material fracture properties can be low;
e. stresses which, combined with the environment, result in reduced fracture resistance.

If, as a result of the assessment, there is no obvious ranking in criticality, a sufficient number of locations shall be analysed to permit the criticality of the item to be defined.

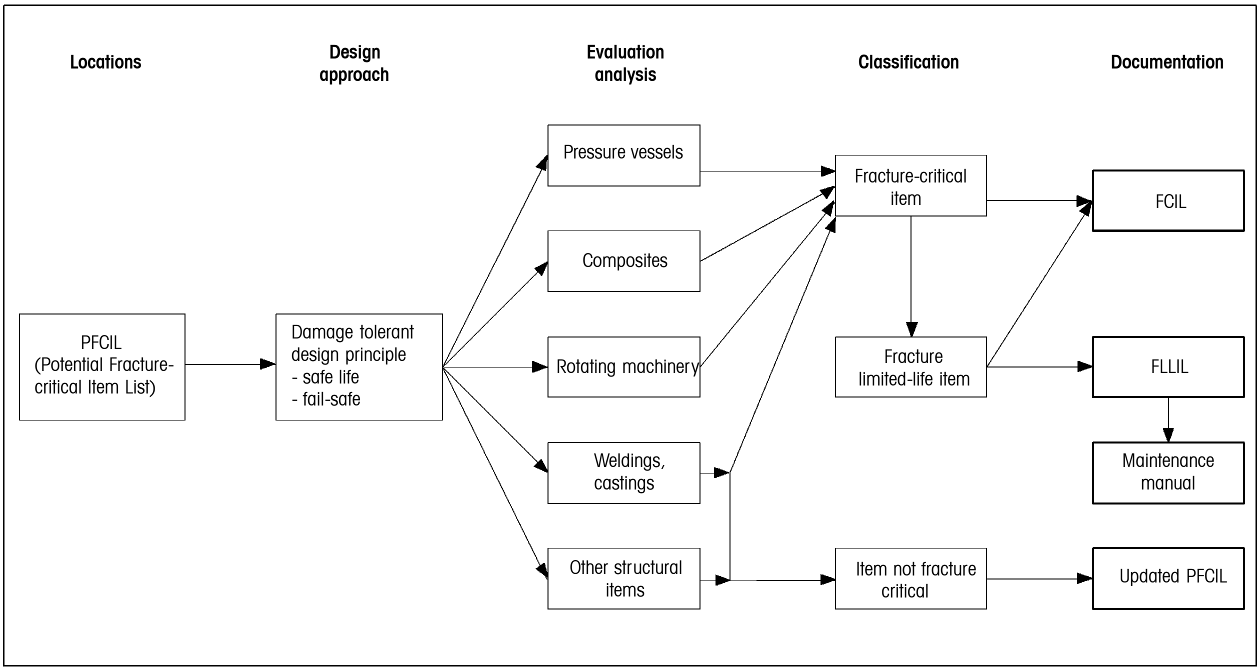

Figure 2: Fracture control procedures

6.2.3 Damage tolerant design

There are two ways of implementing damage tolerance:

a. Safe life

A PFCI is a safe life item if it can be shown that the greatest defect in the part will not grow to such an extent that the minimum specified performance (for example the limit-load capability or no-leak) is no longer assured within a safe life interval. The maximum sustained stress-intensity factor K_{max}, shall not exceed the threshold stress-intensity factor for stress-corrosion cracking K_{ISCC}.

b. Fail-safe

A PFCI is a fail-safe item if it can be shown by analysis or test that, as a result of structural redundancy, the structure remaining after failure of any element of the PFCI can sustain the new higher loads with a safety factor 1,0 without losing limit-specified performance. In addition, the failure of the item shall not result in the release of any part or fragment which results in an event having catastrophic or critical consequences or which has a mass in excess of that stated as allowable in subclause 6.2.1 of this Standard.

6.2.4 Classification

The results of the safe life or fail-safe analysis, the type of non-destructive inspection used and the type of material used shall determine whether or not PFCIs are identified as fracture-critical items.

A fracture-critical item (FCI) is defined as any of the following:

a. any item which requires NDI better than standard NDI, as defined in subclause 10.3;

b. any pressure vessel as defined in subclause 8.1;

c. any item which requires periodic re-inspection in order to achieve the required life. Such items are called fracture limited-life items (FLLI) as a subset of FCI;

d. any composite or non-metallic PFCI, unless contained.

6.3 Compliance procedures

6.3.1 Safe life items

The evaluation procedure to be followed for a PFCI considered as a safe life item is specified in Figure 3.

The term: “two flights” is required in order to take into account one aborted flight, i.e. the service life shall as a minimum include two ascent and one descent flight events.

6.3.2 Fail-safe items

The evaluation procedure to be followed for a PFCI considered as fail-safe item is specified in Figure 4.

6.3.3 Contained items

It shall be demonstrated by analysis or test that the release of any loose item which can lead to a hazard having serious or catastrophic consequences will be effectively prevented.

For payloads of the NASA STS or ISS, it shall be shown by analysis or test that any loose item exceeding the allowable mass defined in subclause 6.2.1 will be prevented from being released into the cargo bay or crew compartments.

6.4 Documentation requirements

The following documents shall be prepared and submitted to the customer for approval.

6.4.1 Lists

a. Potential fracture-critical item list

The potential fracture-critical item list (PFCIL) shall be compiled from the results of the fracture control screening and shall identify the item name, drawing number, material, design principle and required NDI (method/level) for each item.

b. Fracture-critical item list

The fracture-critical item list (FCIL) shall include the same information as the PFCIL. In addition, the FCIL shall specify a reference to the document which shows for each item the fracture analysis and/or test results and the analytical life.

c. Fracture limited-life item list

The fracture limited-life item list (FLLIL) shall include the same information as the FCIL. In addition, the FLLIL shall specify the inspection method and period, and shall identify the maintenance manual in which inspection procedures are defined.

NOTE The above three lists may be reported in one document.

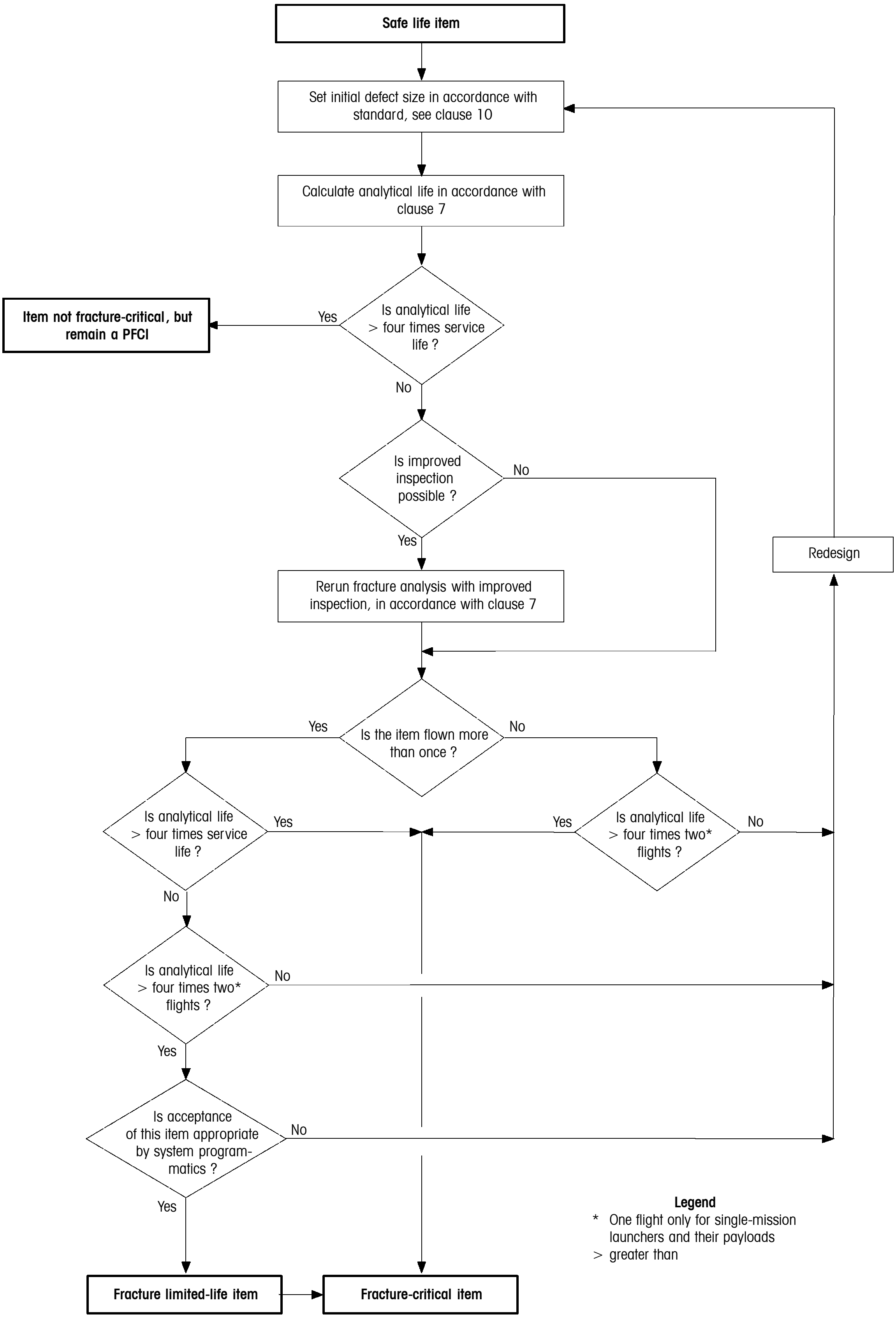

Figure 3: Safe life item evaluation procedure

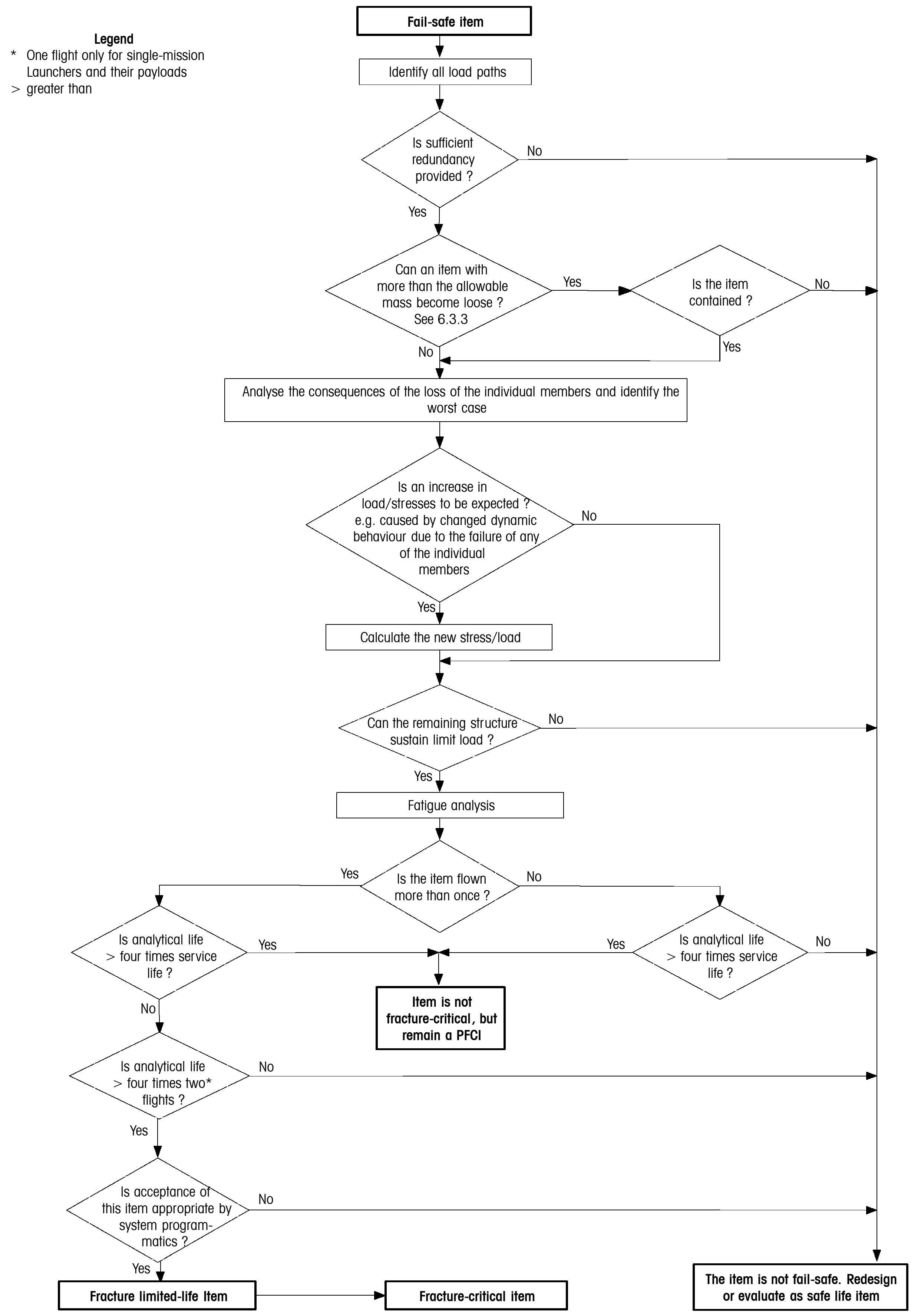

Figure 4: Evaluation procedure for fail-safe items

6.4.2 Analysis and test documents

An analysis of all PFCIs shall be performed and documented. When testing is used in addition to analysis the test method and test results shall also be documented.

The analysis and test documentation shall as a minimum contain the following:

a. For safe life items:

   1. A description of the item with identification of material (alloy and temper), grain direction, and a clear sketch showing the size, location and direction of all assumed initial cracks.
   2. A description of the analysis performed, including:
      - a reference to the stress report;
      - the loading spectrum and how it has been derived;
      - material data and how they have been derived;
      - environmental conditions;
      - stress intensity factor solutions and how they have been derived;
      - critical crack size;
      - analytical life.
   3. A summary of the significant results.

b. For fail-safe items:

   1. A description of the item;
   2. Failure modes assumed;
   3. Stress analysis with new loading distribution of the failed configurations and safety factor of 1,0;
   4. Fatigue analysis of the most critical item;
   5. A summary of the significant result.

c. For contained items:

   1. A description of the assumed container, the assumed projectile dimensions, and the material-properties employed in the analysis.
   2. A containment analysis, which includes the derivation of:
      - the velocity and energy of the projectile as it strikes the container;
      - all maximum forces or stresses in attachments, brackets and other relevant items occurring during impact;
      - a summary of the significant results.

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7

Fracture mechanics analysis

7.1 General

Fracture mechanics analysis shall be performed to determine the analytical life of a safe life item in accordance with the requirements of this clause. The data required to permit crack growth prediction and critical crack-size calculation are as follows:

a. stress distribution;

b. load spectra;

c. material properties;

d. initial crack size;

e. stress intensity factor solutions.

7.2 Analysis

a. For the fracture mechanics analysis, the software package ESACRACK may be used. This package comprises the ESALOAD software, which generates load spectra, the fracture mechanics software NASGRO (NASA/FLAGRO), which includes a materials data base and the ESAFATIG software for fatigue analysis.

NOTE 1 The software package ESACRACK may be obtained from Mechanical Systems Division, ESA.

NOTE 4 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.

b. In cases where it is not planned to use ESACRACK, alternative analysis procedures may be used if they are shown to give comparable results. Alternative analysis procedures shall be submitted to the customer for approval prior to their use.

c. A fracture mechanics analysis shall include the following two items:

1. crack-growth calculation;
2. critical crack-size calculations.

7.2.1 Analytical life prediction

Analytical life prediction shall be performed on the basis of crack-growth analysis, which includes:

a. Identification of all load events experienced by the item in question

The service-life profile shall be clearly defined, in order to identify all cyclic and sustained load events. The following events shall be considered:

1. manufacturing/assembly;
2. testing;
3. handling, e.g. by a dolly or a hoist;
4. transportation by land, sea and air;
5. ascent;
6. stay in orbit, including thermally induced loads;
7. descent;
8. landing.

b. Identification of the most critical location and orientation of the crack on the item.

For each item only the most critical location and orientation of the crack needs to be analysed. To identify the most critical location, stress-concentration, environmental and fretting effects shall be considered (see also subclause 6.2.2). 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 such that the criticality of the item can be defined.

c. Derivation of detailed stresses for the critical location.

For the critical location, stresses in X-, Y- and Z-direction, including temperature and pressure stresses, shall be derived. For pressure vessels, both primary membrane and secondary bending stresses resulting from internal pressure shall be calculated to account for the effects of design discontinuities and design geometries. Where applicable, rotational accelerations shall be considered in addition to translational accelerations. Residual stress due to fabrication, assembly, welding, testing or preloading shall also be included.

d. Derivation of a stress spectrum by use of the load events identified under *a* and the stresses derived under c.

A stress spectrum shall be generated for each analysis location, and shall include the stresses for all loading events which occur throughout the service life. Each stress step in the stress-spectra has to contain the number of cycles in the step, the upper value of the stress amplitude and the lower value of the stress amplitude.

e. Derivation of material data.

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

1. mean values of crack growth rate, da/dN, da/dt;
2. mean value of threshold stress intensity range, K_{th};
3. Lower boundary values, defined as 70 % of mean values for:
   (a) critical stress intensity factor, K_{IC} or K_C (fracture toughness);
   (b) environmentally controlled threshold stress intensity for sustained loading, K_{ISCC};

4. Upper boundary values, defined as 1,3 times the mean values, shall be used for the critical stress intensity factor, K_{IC} or K_C, when proof loading is used for identification of initial crack sizes.

The material data in the NASA/FLAGRO database are mean values, and a reduction as described above shall therefore be applied for the toughness parameters. (A reduction option is implemented in the ESACRACK software.)

For some materials a significant reduction of the K_C for thin sheets has been observed, and this effect shall be considered.

f. Identification of the initial crack size and shape.

The initial crack shape shall be identified by considering the geometry of the item and the critical location. The analysis shall be based, where applicable, on the geometry and crack shapes shown in clause 10, Figures 6 and 7. The initial crack sizes used in the analysis shall be consistent with the inspection level or proof load screening used for the item. The analysis shall consider crack aspect ratios (a/c) of 0,2 and 1,0.

g. Identification of an applicable stress intensity factor solution.

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

h. Performance of crack growth calculations.

Crack growth calculations shall be performed, using the variables as defined above. The 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, as required. The complete loading spectrum shall be analytically imposed at least four (4) times in sequence, one after another.

Beneficial retardation effects on crack growth rates from variable amplitude loading shall not be considered without the approval of the responsible fracture control authority.

For components where it is necessary to consider the propagation of a crack into a hole, the analysis shall assume that crack propagation is not arrested or retarded by the hole.

7.2.2 Critical crack-size calculation

The critical crack-size (a_c), defined as the crack size at which the structure fails under limit load, shall be calculated for brittle fracture as follows:

$$a_c = \frac{(K_C)^2}{\pi(\Sigma F_i S_i)^2}$$

where S_i are the limit stresses and F_i are the stress intensity magnification factors for the different load cases and K_C is the critical stress intensity factor. The factors F_i normally depend on the crack size a, and this effect shall be accounted for in the calculations, e.g. by use of an iterative method.

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8

Special requirements

8.1 Pressurised systems

8.1.1 General

Pressurized systems, including pressure vessels, pressure lines, fittings and components, and sealed containers shall be designed and verified according to the requirements of this subclause 8.1. In addition, all pressurized systems in NSTS and ISS payloads shall conform to the requirements of NSTS 1700.7 (incl. ISS Addendum).

8.1.2 Pressure vessels

A pressure vessel is a pressurized container which:

- contains stored energy of 19310 joules (14240 foot-pounds) or more, the amount being based on the adiabatic expansion of a perfect gas; or
- contains a gas or liquid which will create a hazard if released; or
- will experience a maximum design pressure (MDP) greater than 0,69 MPa (100 psi).

a. Pressure vessels shall always be classified as fracture critical and shall always be subject to the implementation of fracture critical item tracking, control and documentation procedures.

b. The design of a pressure vessel shall account for pressures, temperatures, internal and external environments, and stresses whether imposed by internal or external forces or other sources of stress to which the vessel can be exposed. Representative or conservative load combinations shall be applied.

c. Pressure vessels shall conform to MIL-STD-1522A, November 1986, with the following modifications:

   1. The use of paragraphs 5.1.3 and 5.2.3 of MIL-STD-1522A (i.e. the strength-of-materials oriented Approach B of Figure 2) is not acceptable;
   2. The use of paragraphs 5.1.4 and 5.2.4 of MIL-STD-1522A (Approach C of Figure 2, i.e. the ASME code or DOT TITLE 49) is only acceptable after concurrence of the customer;
   3. The use of the appendix to MIL-STD-1522A is not acceptable;

4. Maximum Design Pressure (MDP) as defined in subclause 3.1 of this standard, shall be substituted for all references to Maximum Expected Operating Pressure (MEOP). In addition, vehicle acceleration loads shall be included;
5. A fracture mechanics analysis of pressure vessels shall, when required by the documents referred to above, be performed in accordance with the procedure set out in Figure 5 of this Standard and with the requirements of clause 7 of this Standard. Crack aspect ratios in the range of $0,2 < a/c < 1,0$ shall be included.

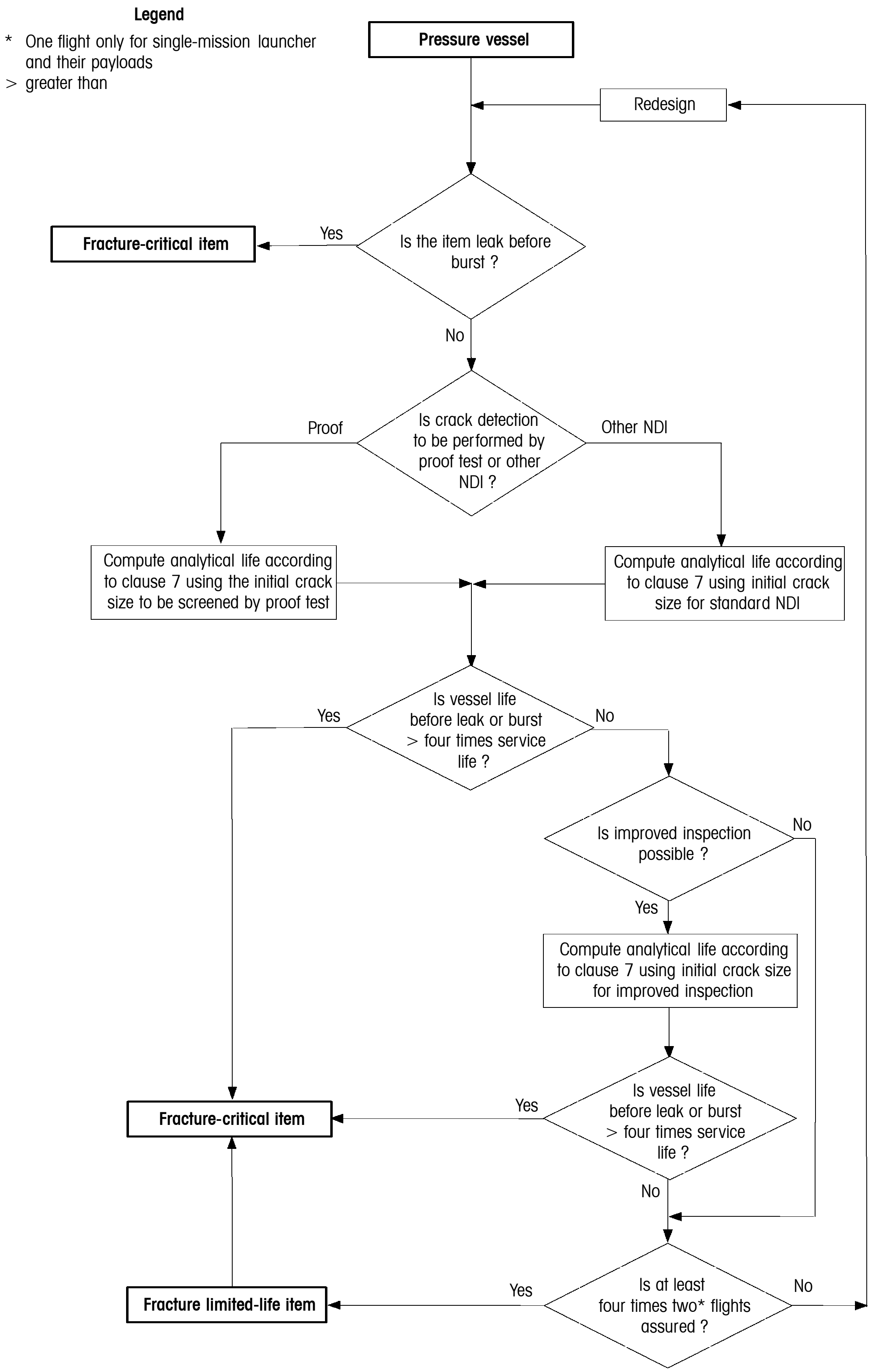

Figure 5: Logic for pressure vessel evaluation

8.1.3 Pressure lines, fittings and components

a. For pressurized items other than pressure vessels, the complete pressure system shall be proof tested and leak checked in addition to an acceptance proof test of the individual items.

b. Safe life analysis is not required if the item is proof tested to a level of 1,5 or more times the limit load, including MDP and vehicle accelerations.

c. All fusion joints shall be 100 % inspected according to the appropriate section of Table 2 by means of a qualified NDI method. Concurrence of the customer is required where 100 % NDI is not considered practicable.

8.1.4 Sealed containers

A sealed container is a pressurized container, compartment or housing that is individually sealed to maintain an internal gaseous environment, but does not classify as a pressure vessel according to subclause 8.1.2.

Sealed containers meeting the following criteria shall be acceptable without further assessment:

a. The container is not part of a system with a pressure source and is individually sealed.

b. Leakage of the contained gas does not result in a catastrophic hazard.

c. The container/housing is made from a conventional alloy of steel, aluminium, nickel, copper or titanium.

d. The MDP does not exceed 151,98 kPa.

e. The free volume within the container does not exceed 0,0509 m^3 (1,8 cubic feet) at 151,98 kPa or 0,0764 m^3 (2,7 cubic feet) at 101,325 kPa, or any pressure/volume combination not exceeding a stored energy potential of 19310 joules (14240 foot-pounds).

Sealed containers with a MDP higher than 151,98 kPa, but less than 689,01 kPa, and a potential energy not exceeding 19310 joules (14240 foot-pounds) are also acceptable if the minimum factor of safety is 2,5 × MDP, an acceptable stress analysis on test has been performed, and requirements a, b, and c above are met.

In addition to the criteria presented herein, all sealed containers shall be capable of sustaining 101,325 kPa pressure with a minimum safety factor of 1,5.

8.2 Welds

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

b. When such material properties are not available, they shall be derived by means of a test programme covering:

   1. ultimate and yield strength and Young's modulus for all welding conditions used, including mechanical properties (as above) in the presence of different mismatches, angles between joints or typical defects, so that their impact on the material degradation can be evaluated with respect to the strength requirements;

   2. the fracture toughness K_C, the stress-corrosion cracking threshold K_{ISCC}, and crack propagation parameters for each type of thickness to meet the requirements for structural integrity and leak-before-burst, if applicable.

   These tests shall be performed on a sufficient number of specimens agreed with the customer to permit a statistical evaluation of final values.

c. Any residual stresses, both in the weld and in the heat-affected zone, shall be accounted for.

d. Even though inspected for embedded cracks, the initial crack geometry for the analysis shall always be assumed to be a surface part-through-crack or through-crack, as defined in clause 10.

8.3 Composites

Potential fracture critical items made of fibre-reinforced composite or non-metallic material including bonded joints and potted inserts, other than glass, shall be treated as fracture critical items. They shall comply with the following requirements:

a. For fail-safe items:

An item shall not be accepted as a fail safe item unless:

1. it meets all the requirements for the fail safe approach described in subclauses 6.2 and 6.3; and
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.

b. For safe life items:

An item shall not be accepted as a safe life item unless:

1. it has been demonstrated by fatigue analysis 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 NDI techniques. Tests shall be performed with 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.

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 shall be treated on a case by case basis.

The test and analysis programme is subject to customer approval.

8.4 Rotating machinery

Rotating machinery shall be proof (spin) tested and subjected to NDI before and after proof testing. The proof test factor shall be derived by means of fracture mechanics analysis.

Rotating hardware not defined as rotating machinery according to 3.1.33 shall be treated as any structural item.

8.5 Glass

a. The design of all potential fracture critical glass components shall include an evaluation of flaw growth under conditions of limit stresses and the environments encountered during their service life.

b. A fracture mechanics analysis for possible sustained crack growth (da/dt) shall be performed for each glass item. This analysis shall demonstrate that the item sustains after four (4) times its service life at least one and four tenths (1,4) times the design limit load without fracture.

c. The initial flaw depth used for design and analysis of glass items:

1. shall not be smaller than three (3) times the detectable flaw depth based on the NDI methods used;
2. shall be subject to approval by the customer.

Long flaws with respect to depth shall be used for analytical life predictions. When using ESACRACK, the aspect ratio a/c = 0,1 shall be applied. Crack growth properties at 100 % moisture shall be used for life predictions.

d. Proof testing or NDI, consistent with the loading expected during service life, shall be conducted to screen for manufacturing flaws in each potential fracture-critical item based on the result of the fracture mechanics analysis.

e. Proof testing is required for acceptance of pressurised glass components (such as windows and viewports) to screen the flaws larger than the initial flaw depth. The minimum proof pressure for these components shall be two (2) times the limit pressure.

   Proof testing shall be performed in an environment suitable to limit flaw growth during test.

f. It shall be demonstrated that glass inside a habitable area shall be safe from breakage, or shall be contained, or released particles shall be smaller than 50 μm. Positive protection for the crew against any breakage or release of shattered material is required.

8.6 Fasteners

a. Fasteners shall be classified and analysed as any other structural item.

b. Fasteners smaller than diameter 5 mm shall not be used in safe life applications.

c. For fasteners equal to or larger than diameter 5 mm, the following requirements apply:

   1. Titanium alloy fasteners shall not be used in safe life applications.
   2. All potential fracture-critical fasteners shall be procured and tested according to aerospace standards or specifications with equivalent requirements.
   3. All safe life fasteners shall be marked and stored separately following NDI or proof testing.

9
Material selection general requirements

a. Materials to be used shall be selected and controlled in accordance with the requirements of ECSS-Q-70 “Materials, mechanical parts and processes”.

b. The material selection process shall take into account structural and non-structural requirements. The materials selected shall possess the appropriate fracture toughness, crack-growth characteristics, and structural properties, such as Young’s modulus and yield strength.

c. Where validated properties required for analysis are not available, or available properties are not validated by standard or other adequate test procedures, an appropriate statistical basis for average and minimum values shall be established from coupon tests.

d. For applications where failure of a material can result in catastrophic or critical hazard, alloys which possess high resistance to stress-corrosion cracking shall be used. (See Table 1 of ECSS-Q-70-36A.)

NOTE 1 Strength, fracture and fatigue properties for a large number of aerospace materials are documented in the ESA developed materials database “FRAMES-2”.

NOTE 5 The materials database ”FRAMES-2” may be obtained from Mechanical Systems Division, ESA.

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10
Quality assurance requirements

10.1 General

Quality assurance requirements as specified in ECSS-Q-20 "Quality assurance" and the materials selection and quality control requirements specified in ECSS-Q-70 "Materials, mechanical parts and processes" are applicable.

10.2 Nonconformances

a. Dispositioning of nonconformances for PFCIs requires reassessment of these items to verify conformance to the fracture control requirements.

b. All nonconformances which affect fracture-critical items and primary structural hardware designed to safe life principles, shall be dispositioned as "major nonconformances" and shall be subject to the disposition of a Nonconformance Review Board defined in ECSS-Q-20-09.

10.3 Non-destructive inspection

10.3.1 General

Relevant non-destructive inspection (NDI) levels shall be categorized as standard NDI, special NDI or proof testing NDI.

10.3.2 NDI categories versus initial crack size

The initial crack sizes as defined in the following shall apply:

- Table 1 defines the initial crack sizes for standard NDI.
- Table 2 defines the initial crack sizes for standard NDI that shall be applied in the case of welds and castings.
- Initial crack geometries are shown in Figures 6 and 7.

a. Standard NDI

This level of inspection requires the use of one or more of the standard industrial NDI techniques: dye-penetrant, X-ray, ultrasonic or eddy current. Visual inspection is not acceptable, except for glass items. Standard NDI shall be performed in accordance with MIL-I-6870 and shall provide crack detection to at least 95 % confidence and 90 % probability level. Tables 1 and 2 give, for various NDI techniques and part geometries, the largest crack sizes that can remain undetected at these probability and confidence levels.

b. Special NDI

This level of inspection shall be used only in special cases where limited life is demonstrated and serious problems can occur as a result of redesign or acceptance of the limited life. A statistical demonstration of 90 % probability and 95 % confidence shall be performed for the method. The demonstration results and resulting procedures shall be subject to customer approval. Such demonstration shall be carried out on specimens representative of the actual configuration to be inspected.

c. Proof testing NDI

Proof testing of a flight item is acceptable as a screening or inspection technique for cracks. However, proof testing can require loads substantially in excess of those usually imposed on flight hardware in order to screen out flaws of sufficiently small size. In the proof tests performed, procedures and stress analysis predictions shall be sufficiently reliable and coordinated to 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.

Proof-test procedures shall be submitted to the customer for approval prior to the start of testing.

Table 1: Initial crack size summary, standard NDI

Crack location	Part thickness t [mm]	Crack configuration number	Crack type	Crack depth a [mm]	Crack length c [mm]
Eddy current NDI					
Open surface	t ≤ 1,27 t > 1,27	4 1, 3, 8	through surface	t 0,51 1,27	1,27 2,54 1,27
Edge or hole	t ≤ 1,91 t > 1,91	5, 9 2, 7	through corner	t 1,91	2,54 1,91
Penetrant NDI					
Open surface	t ≤ 1,27 1,27 ≤ t ≤1,91 t > 1,91	4 4 1, 3, 8	through through surface	t t 0,81 1,91	2,54 3,82 - t 4,05 1,91
Edge or hole	t ≤ 2,50 t > 2,50	5, 9 2, 7	through corner	t 2,54	2,54 2,54
Penetrant NDI of titanium alloys					
Open surface	t ≤ 3,0 t > 3,0	4 1, 3, 8	through surface	t 3,00 1,50	3,00 3,00 7,50
Edge or hole	t ≤ 3,0 t > 3,0	5, 9 2, 7	through surface	t 3,00	3,00 3,00
Magnetic Particle NDI					
Open surface	t ≤ 1,91 t > 1,91	4 1, 3, 8	through surface	t 0,97 1,91	3,18 4,78 3,18
Edge or hole	t ≤ 1,91 t > 1,91	5, 9 2, 7	through corner	t 1,91	6,35 6,35
Radiographic NDI					
Open surface	0,63 ≤ t ≤2,72 t > 2,72	1, 2, 3, 7, 8	surface	0,7 × t 0,7 × t	1,91 0,7 × t
Ultrasonic NDI Comparable to Class A quality level, as defined in MSFC-STD-1249					
Open surface	t ≥ 2,54	1, 2, 3, 7, 8	surface	0,76 1,65	3,81 1,65

NOTE 1 The crack configuration numbers refer to the crack configurations shown in Figures 6 and 7.

NOTE 2 Radiographic NDI defect sizes are not applicable for very tight defects such as: forging defects, heat treatment induced defects, defects in compressive stress field. For such cases special NDI requirements apply.

Table 2: Initial crack summary, standard NDI for welds and castings

NDI TECHNIQUE	Defect: Type	Shape	Crack configuration number	Applicability	Depth a, 2a [mm]	Length c [mm]	Applicable thickness
X-RAY	Pore		6	▷5	2a = 0,7 × t	0,35 × t	all
X-RAY	Inclusion		6	▷1	2a = 0,7 × t and 2a = 0,6 × t	0,35 × t 0,6 × t	all
X-RAY	Incomplete penetration		1, 2, 3	▷2	see Table 1	see Table 1	welds only
X-RAY	Surface crack		-	▷3	see Table 1	see Table 1	
ULTRASONIC	Pore and inclusion		6, 4	applicable	5,2 through and 3,5 through	2,6 2,6 3,5 3,5	t > 5,2 t ≤ 5,2 t > 3,5 t ≤ 3,5
ULTRASONIC	Incomplete penetration		1, 2, 3, 4, 5	applicable	3,5 through and ▷4 1,65 through	3,5 3,5 8,25 8,25	t > 3,5 t ≤ 3,5 t > 1,65 1,0 ≤ t ≤ 1,65
ULTRASONIC	Surface crack		1, 2, 3, 4, 5	applicable	3,5 through and ▷4 1,65 through	3,5 3,5 8,25 8,25	t > 3,5 t ≤ 3,5 t > 1,65 1,0 ≤ t ≤ 1,65
PENETRATE	Pore		-	not applicable			
PENETRATE	Incomplete penetration		-	not applicable			
PENETRATE	Incomplete penetration		1, 2, 3, 4, 5	▷2	a = 3,0 and a = 1,5	c = 3,0 c = 7,5	t > a ▷5
PENETRATE	Surface crack		1, 2, 3, 4, 5	applicable	a = 3,0 and a = 1,5	c = 3,0 c = 7,5	t > a ▷5

t — thickness during application of X-ray

▷1 — only if elliptical geometry is determined (no geometry with sharp corners acceptable)

▷2 — applicable to welds only

▷3 — not applicable for standard inspection

▷4 — support by surface sensitive inspection recommended (e.g. penetrant inspection)

▷5 — for t ≤ a applying through crack

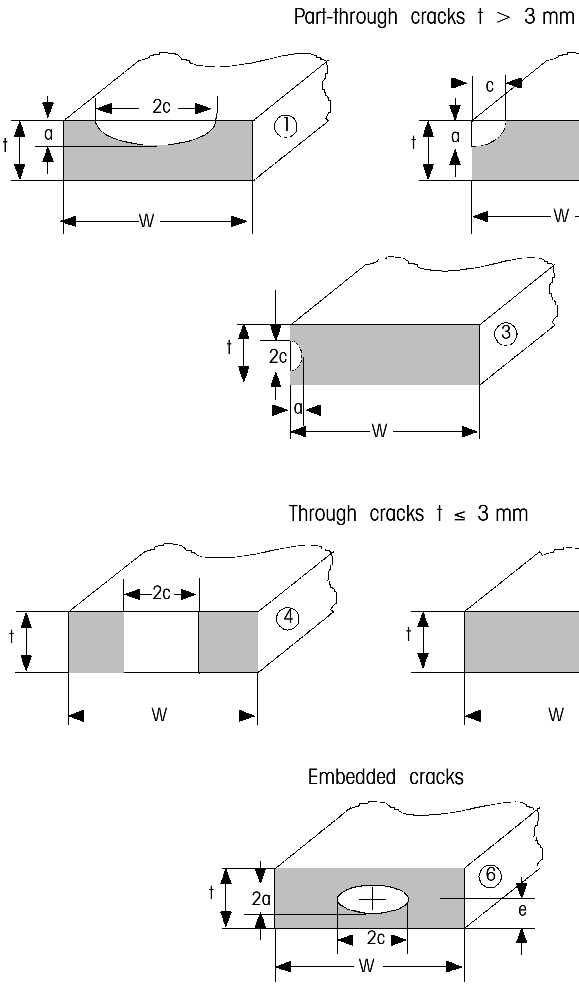

Figure 6: Initial crack geometries for parts without holes

10.4 Inspection requirements

The fracture control programme requires inspection of all PFCIs in order to validate the analytical life predictions and to permit hardware to be released as acceptable. Such inspection shall include at least:

a. Inspection of raw materials for all safe life and fail-safe items to ensure absence of embedded defects larger than the assumed initial defect sizes.

b. Initial inspection of all finished items by the NDI method (subclause 10.3) relevant to the assumed initial crack size. The NDI shall be performed for the total item even though only one location is analysed. Items to be inspected using dye-penetrant, shall have their mechanically disturbed surfaces etched prior to inspection. Rolled threads shall not be etched.

c. Inspections as may be required for limited life items.

d. Verification of structural redundancy for fail-safe items before each flight.

e. Post test NDI for all proof-tested items. Concurrence of the customer is required where post proof test NDI is not considered practicable.

f. Inspection of all welds shall include a search for surface defects as well as embedded defects.

g. 100 % inspection of all fusion joints of pressurized lines before and after proof test, using a qualified NDI method.

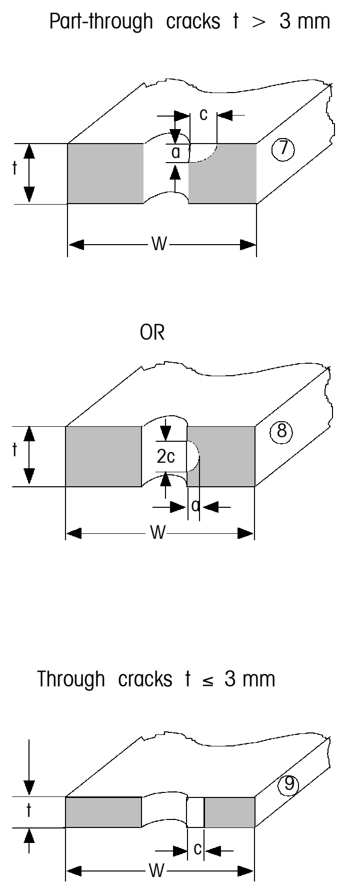

Figure 7: Initial crack geometries for parts with holes

h. Applicable NDI requirements shall be stated on design and manufacturing documentation.

Inspection shall be performed by qualified personnel, certified for the relevant inspection method, in accordance with MIL-STD-410 or equivalent.

Special jigs, fixtures and non-standard equipment needed to perform re-inspection shall be deliverable with the fracture-critical items.

10.5 Traceability

10.5.1 General

Traceability of structural materials and items shall be implemented to provide assurance that the material used in the manufacture of structural hardware has properties fully representative of those used in the analysis or verification tests.

Traceability shall also provide assurance that structural hardware is manufactured and inspected in accordance with the specific requirements necessary to implement the fracture control programme. The traceability requirements of ECSS-Q-20 shall be applied.

10.5.2 Requirements

The following traceability requirements apply:

a. All associated drawings, manufacturing and quality control documentation shall identify that the item is a potential fracture-critical item;

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

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

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;

e. For each fracture-critical item a log shall be maintained, which documents all loadings due to testing, assembly and operation, including torquing of fasteners.

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11

Reduced fracture control programme

11.1 General

For unmanned, single-mission, space vehicles and their payloads, a reduced fracture control programme (RFCP) as defined in this clause shall, as a minimum, be implemented.

11.2 Requirements

A reduced fracture control programme shall satisfy all requirements given in this standard, with the modifications defined below:

a. Subclause 6.1 (Identification of PFCIs)

   The identification of PFCIs shall 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.

b. Identification of potential fracture-critical items

   The identification of potential fracture-critical items shall be performed according to the procedure given in Figure 1.

c. Subclause 6.4 (Documentation requirements)

   The information required in subclause 6.4.1 may be consolidated into one list; separate lists are not required.

d. Subclause 8.3 (Composites) and subclause 8.5 (Glass)

   The requirements of these two subclauses shall be replaced by the following requirement: non-metallic structural items shall be proof-tested at 1,2 times the limit load.

e. Subclause 8.4 (Rotating machinery)

   The requirements of this subclause shall be replaced by the following requirement: rotational machinery (wheels and gyros) shall be proof-spin-tested at one and one tenth (1,1) times nominal operational speed.

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Annex A (informative)

Document Requirements Definition index

DRD Title

Fracture Control Plan

Potential Fracture-Critical Items List

Fracture-Critical Items List

Fracture Limited-Life Items List

Fracture Analysis and Test Reports

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Annex B (informative)

ESACRACK software package

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 allows the user to:

- generate load and stress spectra (ESALOAD);
- perform fracture mechanics analysis (NASFLA);
- generate stress intensity factor solutions (NASBEM);
- process crack growth material data (NASMAT);
- perform fatigue analysis (ESAFATIG)

The various analysis tools can be accessed through the ESACRAK3 main program. Detailed user manuals, Issue 2 (January 1995) include the three modules ESALOAD, NASGRO and ESAFATIG.

The source code modules are all (except ESACRAK3 main program) written in standard FORTRAN 77 to ensure portability between different platforms. The main program, ESACRAK3, is written in C.

Currently, the software package is available for PCs (80386 and upwards), VAX/VMS and UNIX machines. A certain degree of platform dependency does exist, however, and this may necessitate some minor source code modifications.

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ECSS Document Improvement Proposal

1. Document I.D.	2. Document Date	3. Document Title
ECSS-E-30-01A	13 April 1999	Fracture control
4. Recommended Improvement (identify clauses, subclauses and include modified text and/or graphic, attach pages as necessary)		
5. Reason for Recommendation		
6. Originator of recommendation		
Name:	Organization:	
Address:	Phone: Fax: E-Mail:	**7. Date of Submission:**
8. Send to ECSS Secretariat		
Name: W. Kriedte ESA-TOS/QR	Address: ESTEC, Postbus 299 2200 AG Noordwijk The Netherlands	Phone: +31-71-565-3952 Fax: +31-71-565-6839 E-Mail: wkriedte@estec.esa.nl

Note: The originator of the submission should complete items 4, 5, 6 and 7.

This form is available as a Word and Wordperfect-Template on internet under http://www.estec.esa.nl/ecss/improve/

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