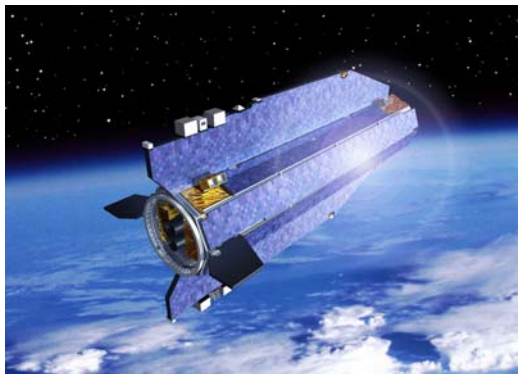

Fracture Control Workshop

What's New in the New Fracture Control Standard ECSS-E-ST-32-01C?

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The New ECSS-E-ST-32-01C

ECSS-E-ST-32-01C
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EUROPEAN COOPERATION
ECSS
FOR SPACE STANDARDIZATION

- Available at: www.ecss.nl (requires registration)
- Alternatively: ESA Requirements and Standards Division ESTEC, P.O. Box 299, 2200 AG Noordwijk The Netherlands
- Note: for related DRDs see ECSS-E-ST-32C 'Structural general requirements'

Space engineering

Fracture control

The New ECSS-E-ST-32-01C

- **Working group members:**
  - G. Sinnema (ESA) – Convenor
  - D. Aliaga (EADS)
  - M. Biagi (CNES)
  - T. Ghidini (ESA)
  - T. Henriksen (ESA)
  - S. Ottaviano (TAS-I)
  - M. Vorel (Astrium)
  - M. Windisch (MT-Aerospace)
- **Former working group members:**
  - G. Bussu (ESA)
  - R. Köper (Astrium)

The New ECSS-E-ST-32-01C - History

- **ECSS-E-ST-32-01C is the successor of ECSS-E-30-01A (1999) and ESA PSS-01-401 (iss.2, 1994)**
- **In addition, the following fracture control requirements exist in specific ESA programmes:**
  - ISS elements like Columbus module, ATV vehicle: MS-ESA-RQ-008 "Fracture Control Requirements (Manned Spaceflight)" (Iss.2B; 1995) For ATV vehicle, these requirements are flown down to ATV-AS-SSS-1100 "ATV System Support Specification - Structure Design, Sizing And Test Specifications" (Appendix 3).
  - Launchers: A5-SG-1-X-10-ASAI "Structure Design, Dimensioning And Test Specifications" (Ariane 5, Vega)

The New ECSS-E-ST-32-01C - History

- **ECSS standard development process:**
  - Draft prepared by Working Group
  - Public Review
  - Update by WG to incorporate results of the public review
  - Approval by ECSS Technical Authority
- **Coordination with recent developments in fracture control standardization at NASA, e.g. reflected in**
  - NASA-STD-5019, Fracture Control Requirements For Spaceflight Hardware (2008)
  - NASA-STD-5009, Nondestructive Evaluation Requirements For Fracture-critical Metallic Components (2008), and
  - MSFC-RQMT-3479, Fracture Control Requirements for Composite and Bonded Vehicle and Payload Structures (2006).
- **ECSS-E-ST-32-01C is now on the list of ESA of approved standards (December 12, 2008)**
  It will therefore be made applicable to new ESA projects

The New ECSS-E-ST-32-01C

- **For document requirement definitions (DRDs) of fracture control documentation, reference is now made to ECSS-E-ST-32 (current version ECSS-E-ST-32C, rev.1, November 15, 2008). This concerns:**
  - Fracture Control Plan (Annex F),
  - Fracture Control Analysis (FCA) (Annex E),
  - Fracture Control Items Lists (PFCIL, FCIL, FLLIL) (Annex G).
- **Coherence with other structural ECSS standards has been checked. Examples:**
  - ECSS-E-ST-32C, Space engineering - Structural general requirements
  - ECSS-E-ST-32-02C, Space engineering - Structural design and verification of pressurized hardware
- **Substantial editing of the existing text to comply with ECSS drafting rules.**

What is Fracture Control?

- **The purpose of Fracture Control is to ensure that undetected cracks and other defects do not lead to failure within the service life of critical hardware.**
- **This can be done by assuming one of the following:**
  - The largest single crack that can be undetected by the applied Non-Destructive Inspection (NDI) method, and show that it does not grow to a critical size within the service life (safe life)
    Examples: crack in main structural item, in pressure vessel wall;
  - Failure of an item (i.e. assuming the largest possible single crack that can exist in a structural element), and show that the remaining structure is sufficient to withstand the applied loads during the remaining service life (fail-safe).
    Examples: bolt failed, lug failed, strut or beam failed.
  - Alternative approaches like containment, low risk, …
- **Fracture Control assumes a structure that is of good quality: the existence of cracks must be exceptional.**
  Detected flaws must be treated with care (i.e. normally avoided).

Scope of ECSS-E-ST-32-01C

- **The fracture control programme is applicable for space systems and related GSE when required by ECSS-Q-ST-40 or by the NASA document NSTS 1700.7, incl. ISS addendum.**
  - ECSS-Q-ST-40C is expected in February 2009. Currently: ECSS-Q-40B (Product Assurance - Safety)
- **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).**
  - For ECSS-E-30-01A this is covered by NASA JSC/ESA-ESTEC Reciprocal Fracture Control Agreement. Update of this agreement to include ECSS-E-ST-32-01C is in progress.

6.3.5 – Low-risk fracture items are introduced

- **Composite low-risk fracture items: see separate presentation**
- **Metallic low-risk fracture items requirements are primarily based on NASA-STD-5003 (Fracture Control Requirements For Payloads Using The Space Shuttle)**
  - Restricted to items with stress < 0.3 x σ_U.
  - Materials shall be procured in conformance with an aerospace standard or equivalent standard approved by the customer
  - Items are not fabricated using a process that has a recognized risk of causing crack-like defects, such as welding, forging, casting, or quenching heat treatment
  - Multi-mission items: crack growth analysis with a=c=3mm
  - Fasteners are not included (fail-safe verification is preferred)
  - Low risk sealed containers are in 8.2.5
- **Note: 'low risk' = 'high quality'**

6.4.4 – Fracture control summary report

- **A fracture control summary report shall be provided with each deliverable flight hardware item (requirement previously contained in ESA GPQ-010 product assurance document)**
- **The fracture control summary report shall contain the following:**
  - Summary of identified PFCI, FCI, FLLI and applied NDI methods, with specific reference to: low risk fracture PFCI, pressurized PFCI, safe life fasteners, composite PFCI, bonded PFCI, sandwich PFCI, glass and other shatterable/brittle PFCI, other non-metallic PFCI, and detected defects that remain in PFCI.
  - A summary discussion of alternative approaches or specialised assessment applied and tests performed.
  - A statement that inspections or tests specified for fracture control were, in fact, applied in conformance with requirements, and that the proper use of the approved materials has been verified.
  - A statement that hardware configuration of PFCI and their assemblies has been physically verified.
  - References to supporting documentation.
    - For example, analysis reports, test reports, NDI reports, structural screening results and associated lists.

7 – Fracture mechanics analysis

- **7.1.c. For the fracture mechanics analysis, the latest version of the software package ESACRACK may be used.**
  - NOTE Additional information on this software package can be found in Annex A, which also addresses some of the limitations of this software.
  - NOTE Update of the existing analysis using the latest version is normally performed, for example, in cases where the analysis is used to support the acceptance of detected defects (see 10.7), or in specific cases where there is a clear indication that the existing analysis made with an older version can be inadequate.
- **7.2.d. In cases where ESACRACK is not used, the alternative methods used and their validation shall be submitted to the customer for approval prior to their use.**
- **NOTE: 6.3.1.b. The methodology applied for evaluation by test shall be subject to customer approval.**
  - Customer approval is specified, because evaluation by test is not specified to the same level of detail than evaluation by analysis. Evaluation by test is similar to evaluation by analysis, where appropriate and not specified otherwise.

7 – Fracture mechanics analysis

- **7.2.5.d. Lower boundary values shall be used, for:**
  1. Critical stress intensity factor, K_{IC} or K_C (fracture toughness), and other residual strength related properties (e.g. flow stress).
  2. Environmentally controlled threshold stress intensity for sustained loading, K_{ISCC}.
- **7.2.5.e. Lower boundary values shall be derived as follows:**
  1. values with a 90% probability and 95% confidence level of being exceeded (B-value as defined in DOT/FAA/AR-MMPDS), or
  2. in cases where insufficient test data are available: 70 % of the mean values.
- **7.2.6.e. Initial crack size for automatic hole preparation, where NDI is performed before hole drilling: requirements introduced similar to existing NASA & ISS requirements.**

7 – Fracture mechanics analysis

- **7.3.b. In those cases outside the range of validity of LEFM, the critical crack size shall be evaluated by appropriate EPFM methods or by a structure representative test.**
  - NOTE This applies also to crack extension under nonlinear material behaviour. For example ductile tearing.
  - NOTE The consideration of structure representative conditions is of great importance in the case of EPFM, where for example stress multi-axiality effects can significantly influence the results of the analysis or test.
  - NOTE In the NASGRO module of the ESACRACK software a simplified verification can be performed to ensure that no premature failure under elastic-plastic conditions occurs, based on comparison of the so-called net-section stress and flow stress. In most of the common applications this can be considered as adequate. For e.g. verification of highly critical, highly stressed (e.g. pressure vessels, launcher tanks) applications and detected defects it can be necessary to performed more advanced EPFM analysis or testing.
- **See also related presentations during this Workshop.**

8.2 – Pressurized hardware

- **Ref. to MIL-STD-1522A is removed. ECSS-E-ST-32-02 is now applicable.**
  Current version ECSS-E-ST-32-02C, rev.1, November 15, 2008
  - 8.2.1.a. All pressurized systems in NSTS and ISS payloads shall be in conformance with the requirements of NSTS 1700.7 (incl. ISS Addendum).
    - For the attachments of pressurized hardware, which are not part of the pressurized shell, no special requirements are specified in 8.2. They follow the normal rules of this standard (e.g. be verified safe life or fail safe) to prevent catastrophic or critical hazards.
  - Important: acc. NSTS 1700.7B (for Shuttle and ISS):
    - Composite Overwrapped Pressure Vessels (COPVs). COPVs shall meet the intent of the pressure vessel requirements in ANSI/AIAA S-081. A damage control plan and stress rupture life assessment are required for each COPV.
- **(8.2.6) Hazardous fluid container requirements are defined i.a.w. NASA-STD-5003**

8.2 – Pressurized hardware

- **8.2.3 Pressurized structures**
  - Pressurized structure: structure designed to carry both internal pressure and vehicle structural loads (E.g. launch vehicle main propellant tanks, crew cabins and manned modules).
  - A pressurized structure shall be classified as a fracture critical item, when it meets the criteria of pressure vessel definition, or when it is the pressure shell of a manned module.
  - The verification shall demonstrate safe life against hazardous leakage and burst.
  - 8.2.3.2 Manned pressurized structures (incl. manned modules)
    - The design of manned pressurized structures shall be in conformance with the leak-before-burst (LBB) criterion.
    - The design shall be safe life to leakage.

Requirements for composite, bonded and sandwich items

- Significantly updated, requirements addressed mainly in 8.4, 10.5, 10.7.
- Major changes are made in order to address the risk of degradation due to impact damage and to complement the existing verification by means of proof testing (also applicable to clause 11).
- More detailed information is provided in dedicated presentation at this Workshop.

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

- **Detailed requirements remain very similar to existing requirements of ECSS-E-30-01A (clause 8.3). However:**
- **8.5.b. Fracture control implementation for PFCI made of non-metallic material shall be subject to customer approval.**
  - It is recognized that for specific cases these rules may not be sufficient or efficient.
  - Example: it may be more appropriate to verify ceramic materials similar to glass, as defined in 8.7.
- **8.5.e. In those cases where problems arise to fulfil the proof test requirement, these shall be treated on a case by case basis.**
  - NOTE For example, the region of high load transfer where compliance with the proof test requirements for the non-metallic structure introduces yielding of the metal component.
- **8.5.f. Test loads on the non-metallic item shall not exceed 80% percent of ultimate strength.**

8.7 – Glass components

- Requirements are updated, resulting in improved coherence with SSP 30560A (International Space Station Program - Glass, Window, and Ceramic Structural Design and Verification Requirements), and other NASA requirements.
- For more detailed discussion of requirements for glass components see dedicated presentation during this Workshop.

8.8 – Requirements for fasteners are updated

- **c. All potential fracture-critical fasteners shall be procured and tested in conformance with aerospace standards for structural fasteners or equivalent specifications agreed with the customer.**
- **d. Fasteners procured and tested in conformance with aerospace standards for non-structural fasteners shall not be used.**
  - Exceptions to be agreed on case by case basis
- **f. Safe life fasteners shall be NDI-inspected by the eddy current method in the shank, head fillet, and thread areas.**
  - This is conform NASA-STD-5003. The related initial crack size a=c=1,91mm is included in NASGRO software.
- **h. Application of rivets shall conform to the requirements for fail-safe items of clause 6.3.2.**

10.3 & 10.4 – Inspection requirements

- **Requirements for NDI are significantly updated and detailed. Some highlights are presented below.**
- **More detailed requirements on standard NDI:**
  - Specific requirements similar to (now obsolete) MSFC-STD-1249, using up to date standards;
  - Requirements for raw material inspection in 10.3.2;
  - Requirements for final item inspection in 10.4.3;
  - Note on penetrant NDI: use fluorescent penetrant, and etch machined surfaces before penetrant inspection.
- **The Table 2 of ECSS-E-31-01A is now deleted (some information is retained in other clauses).**

10.3 & 10.4 – Inspection requirements

- **10.3.1.l. The applied NDI procedures and the justification of their crack detection capability shall be approved by the customer.**
  - NOTE This applies to all NDI procedures applied for implementation of fracture control, including standard NDI procedures. See also 10.4.2.1c.
- **10.4.2.1.c. Implementation of standard NDI on metallic parts based on the crack sizes of Table 10-1 may be performed without a formal demonstration of the crack detection capability specified in 10.4.2.1d.**
  - NOTE The crack size data in Table 10-1 are based principally on NDE capability studies that were conducted on flat, fatigue cracked panels.
    When the component's geometrical features, such as sharp radii, fillets, recesses, surface finish and cleanliness, material selection, reduced accessibility and other conditions can influence the detection capability of the applied standard NDI method, the method is evaluated based on similarity with proven applications or demonstration testing on a small number of samples representative of the minimum detectable crack size.
    This is done to ensure that the detection capability of the applied standard NDI inspection is not influenced.

10.4.2.3 - Crack Screening Proof Test

- NOTE Proof testing can result in the application of loads substantially in excess of those usually imposed on flight hardware in order to screen for cracks of sufficiently small size. This can result in significant risk to damage and reject otherwise acceptable hardware.
- NOTE Requirements for crack growth and critical crack size analysis are specified in clause 7.
  A significant amount of test data can be necessary to validate or complement the analysis results in order to limit the risk of damage to flight hardware.
  Advanced non-linear fracture analysis methodology is normally applied to accurately predict the behaviour of cracks under proof loading, except for e.g. thick-walled items with part-through cracks where the minimum remaining ligament (material thickness ahead of crack tip) is greater than $2{,}5(K_{1c}/\sigma_y)^2$.
  A crack screening proof test of thin-walled items is generally not recommended because of the increased risk of damage due to stable crack growth during the proof test.

10.7 – Detected defects

a. **Safe life and fail safe items with detected defects with a size larger than the following, shall be subjected to additional verification requirements as defined in clause 10.7.2:**
   - The acceptance criteria used in the manufacturing process; or (note: definition of these acceptance criteria is not within scope)
   - 50% of the maximum allowed detectable NDI size in any dimension; or (note this is generally applicable in case of special NDI)
   - 50% of the standard NDI size defined in Table 10-1, for metallic materials

b. **Any PFCI containing detected defects shall not be used without approval of the customer.**
   - NOTE 1 The first option to be considered when a defect is detected in flight hardware is to remove or repair the defect.
   - NOTE 2 For highly critical hardware (especially when used for manned spaceflight), more conservative verification methodology can be requested by the customer (see e.g. NASA-HDBK-5010).

c. **Low risk fracture items shall not contain detected defects.**

10.7 – Detected defects

- **10.7.3 Improved probability of detection**
  - a. If the origin of a detected defect is not uniquely determined and eliminated, and regular occurrence of significant crack-like defects is not excluded by means of improvement of the manufacturing process, an improved NDI method approved by the customer shall be used, such that it provides a probability higher than 90% of detection of unacceptable defects.

11 – Reduced fracture control programme

- **Applicable to unmanned, single-mission, space vehicles and their payloads, and for GSE**
  - 5.1.c. Implementation of fracture control for structural GSE may be limited to items which are not covered by other structural safety requirements.
  - NOTE In many cases this limits fracture control verification to elements directly interfacing with flight hardware.
- **New: 11.2.2.1.a.6. Metallic structural items used in safe life applications, with limit stress levels exceeding 50% of the yield tensile strength of the material.**
  - NOTE When approved by the customer, the scope of this requirement can be reduced to single point of failure items loaded in tension with relatively small cross-section (examples: lugs, iso-static mounts, small strut or pin, GSE interface)
- **Composites, bonded and sandwich items are no longer in 11.**
- **Note: It is important to agree on the hazards to be considered.**

Editorial errors to be corrected in revision 1

- **8.7.c-i: to be rewritten:**
  - c & i combined into new c &d:
    - c. The sustained crack growth analysis shall apply factors to the sustained stresses of the stress spectrum as specified in Table 8 1, depending on the duration of each load event that induces sustained stress.
    - d. The initial crack depth used for design and analysis of glass items shall: …
  - current items d-h become e-i; j-o are obsolete (duplicate)
- **Some references in the bibliography to be moved to normative references:**
  - 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
- **Normative ref. ECSS-E-ST-32A: wrong issue – should be C**
- **11.2.2.1: NOTE 1 applies to everything; NOTE 2 only applies to item 6.**
- **Revision 1 is expected in March 2009**