Fracture control on launchers: Industrial Implementation

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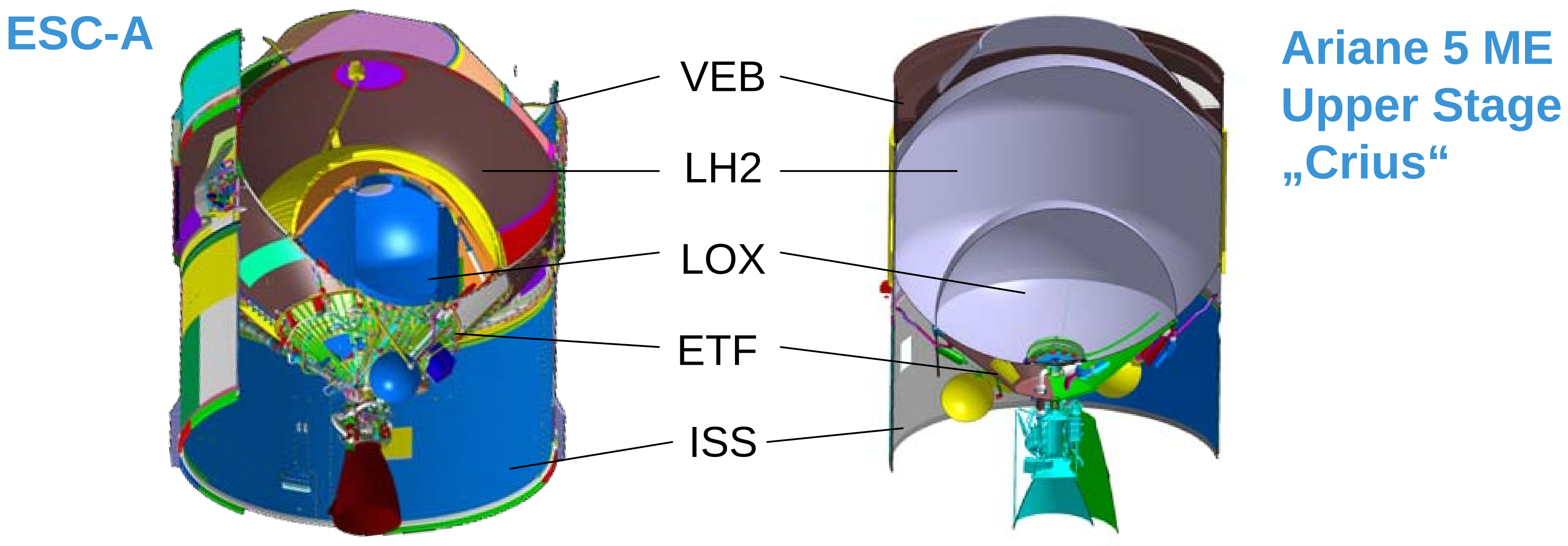
Outline

- Current and upcoming developments
- Fracture Control requirements and approaches
- Comparison of Fracture Control approaches
- Standards SG-1-X-10 and ECSS-ST-32-01
- Organization of Fracture Control activities
- Industrial experience
  - Critical design issues
  - Critical production issues and experience
- Conclusions and Outlook

Current and upcoming developments



- Points critical for fracture control:
  - Generally: geometry, load, material
  - Specifically: location, wall thickness, load type, material, SCC sensitivity

→ pressurized welds, rings, lines, covers, (some) brackets

Fracture control requirements (ESC-A)

- Applicable documents:
  - A5-SG-1-X-10-ASAI: Structure design, dimensioning and test specifications (proprietary)
  - A5-NT-13-X-0008-DASA: Design criteria for ESC-A (proprietary)
    - Contains dedicated requirements for dimensioning and DTA, on top of SG-1-X-10
  - A5-NT-1e6-H-539-CNES: DTA rules for A4 re-flown H/W (propr.)
    - Contains damage tolerance requirements for re-used Ariane 4 components
  - ESA-PSS-01-401: ESA Fracture Control Requirements
- Reference documents:
  - ECSS-E-30-01A: Fracture Control
  - ECSS-Q-70-36A: Material selection for controlling SCC
  - MIL-STD-1522A: Pressurized missile and space systems
  - ANSI/AIAA S-080 + 081: Pressure vessels metallic + COPVs

Fracture control approaches

- ESC-A stage was developed to SG-1-X-10
  - For design issues not contained there ECSS-E-30-01A has been considered
- Crius stage will be developed to the current SG-1-X-10 (same as for ESC-A)
  - → no significant differences in the basic approach
  - For design issues not contained there ECSS-ST-32-01A will be considered

Main issues:

- No PFCIs, FCIs but DJ (~FC Summary), NTs → FC traceability can be optimised
- Safe-life in linear-elastic analysis always required to SG
- Fail-safe analysis performed to ECSS
- Elastic-plastic analysis: not regulated
- SCC requirements (updated data with ECSS, in-house results)
- Only few minor or negligible hazard items, only minimum low risk items

Standard SG-1-X-10

- Current SG-1-X-10 partly obsolete
  - No rules related to structural screening (managed only via RAMS)
  - Only linear-elastic approach, no fail-safe or low risk, SCC very general reqs.
  - No position on material constitutional laws (→ damage mechanics!)
  - Few documentation requirements (essentially NT,DJ)
- New SG-1-X-10 (in draft)
  - Comprises all aspects of structural dimensioning, incl. damage tolerance
  - Defines requirements for <u>both structures and propulsion</u>
  - Most points related to damage tolerance improved (fail-safe / low-risk classifications, points on EPFM, documentation)
  - Classification comparable to ECSS, but less sophisticated logic
  - Less detailed requirements on justification performance and NDI than in ECSS
  - Will not be applicable for Crius, but some features from it will be implemented via dedicated additional requirements

Standard ECSS-ST-32-01

ECSS-E-ST-32-01

- Clean instructions on screening and classification
- Detailed requirements on justification methods (though little on EPFM)
- Detailed requirements on NDI, clearly linked to the sensitivity limits
- Dedicated requirements on particular parts / technologies (welds, castings, fasteners, composites)
- Special attention paid to quality assurance / traceability
- Low risk approach: sensitive issue in view of production stability

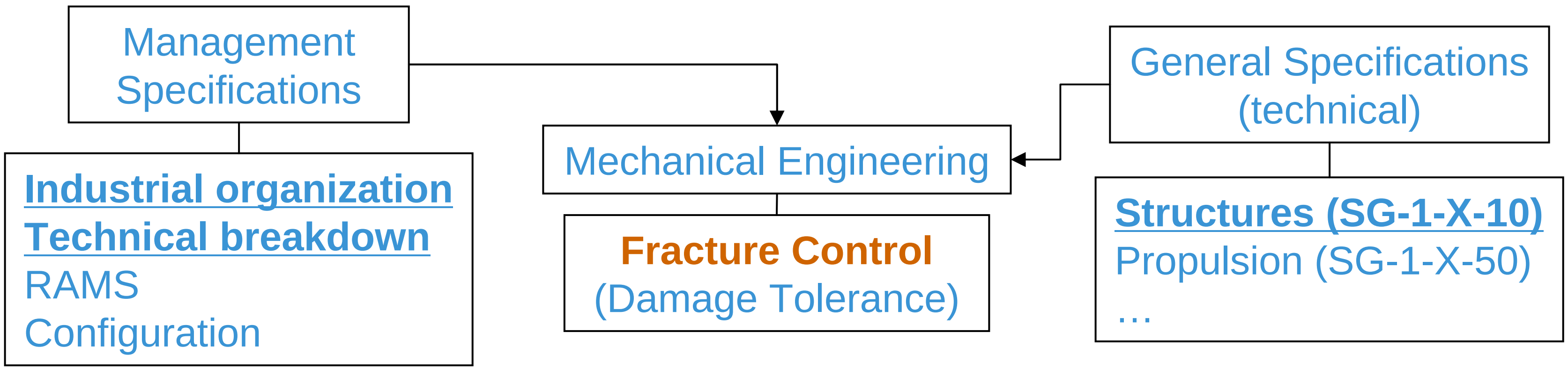
ECSS and ESC-A / Crius

- Direct application difficult: ECSS is too inconsistent with A5 industrial rules, (arrangement of FC activities)
- Technically, most of the contents are directly transferable

- ECSS is related strictly to Fracture Control – SG-1-X-10 comprises the complete dimensioning
- ECSS is related primarily to fracture control of structures – new SG-1-X-10 includes also propulsion

General environment (development phase)

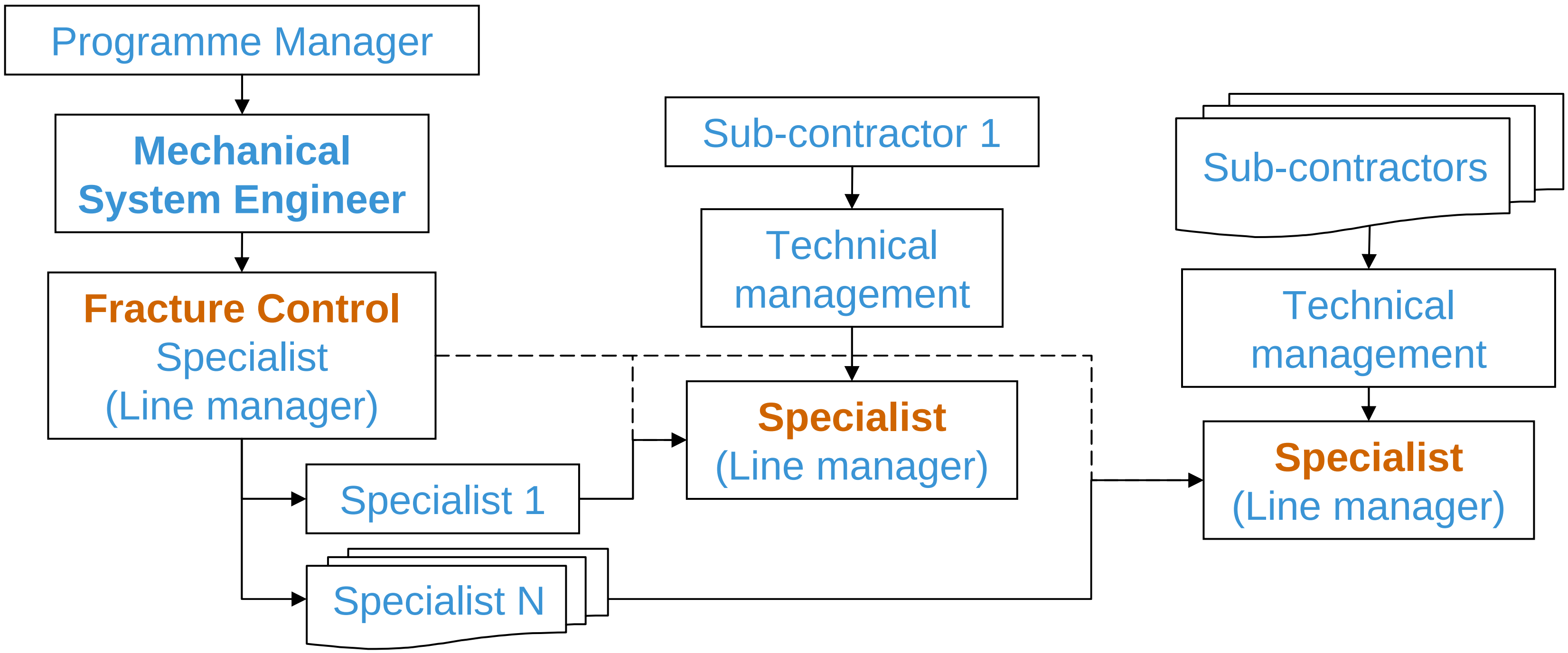
Organization of Fracture Control activities (1)



- Mechanical Engineering activities are regulated via several management specification (SMs)
  - Industrial organization → requirements on technical consistency
  - Technical breakdown → arrangement of engineering
- Mechanical Engineering activities are bound to a certain item and part of the so called constitution list
- Contrary to the NSTS rules: fracture control is not so strongly related to Safety (like e.g. NASA-5019 to NSTS 1700.7), but is viewed as a part of overall structural justification

Practical management (development phase)

Organization of Fracture Control activities (2)



- Fundamental organizational tasks for Fracture Control:
  - Definition of inputs: geometry, loads, preliminary NDI, preliminary material properties
  - Review of outputs: results of DTA, material qualification, NDI qualification

Critical design issues (relevant for development phase)

- Material selection (fracture and crack growth properties, technological properties, SCC)
  - Sometimes obsolete materials (7020,7010)
  - Precise knowledge of the component's envelope life crucial
- Definition of wall thicknesses and local geometry (stress gradient, LBB)
- Reduction of the number of safe-life interfaces (too many safe-life bolts)
- Selection of NDI
  - NDI relevant for the potential defects, realistic assumptions on detection capability
- Feasibility of justification by test
  - When analysis not meaningful, e.g. due to highly complex geometry and/or excessive loading/plastification
- Proper modelling
  - Implementation of new Esacrack/Nasgro versions vital, but sensitive
- Applied elastic-plastic methodology
  - Current SG-1-X-10 does not regulate this issue; ECSS does not give any details on EPFM
  - Further industrialization of damage mechanics models (Rice&Tracey, Gurson, …)
- Robustness of justifications
  - Early and proper identification of relevant processes

Critical production issues (relevant for development and production phases)

▪ **Material production** (casting, working/rolling)	▪ Microstructure similarity, texture ▪ Chemical purity and homogeneity (and its reproducibility) ▪ Mechanical properties isotropy (homogeneity in always one direction)
▪ **Material processing** (forming, machining)	▪ Proper design of the process (relevance of tolerance fields versus over/underthicknesses) ▪ Complex fragmented areas → "fail-safe" milling machines desirable
▪ **Welding and NDI**	▪ Proper design of the process (reasonable elimination of human factor) ▪ Maximum vigilance: with fusion welding human factor especially important, including NDI ▪ Weld repairs are always critical: stability of the nominal welding is crucial
▪ **General quality**	▪ Traceability (running protocols → family building)

- Objectives
  - **To keep the launcher in the authorized (and well-proven) qualification range**
  - To avoid difficult damage tolerance justifications above the defect catalogue (→ robustness)

Fracture Control in future developments

- Further development of the technical basis
  - Consolidation of load spectra (clear I/F to subcos)
  - Early analysis of potential defects (esp. type, origin, size)
  - Unified NDI procedure for evaluation of sensitivity limits
  - Unified standard for SCC testing under propellants
  - Thorough understanding of materials and process characterization
- Particular points:
  - Implementation of Al-Li alloys
  - Implementation of new welding technologies, esp. FSW

  → Challenge in terms of reproducibility (both base material properties and processes, esp. welding and NDI)

→ **Maintaining the validity of Fracture Control justifications may be harder than their initial achievement**

Conclusions and Outlook

- **By its nature Fracture Control takes special responsibility as it closes the loop between dimensioning and the real flight H/W**
  - Despite good design, proper dimensioning and conscientious quality unexpected problems may always occur in the production phase
  - Elimination of human factor has great quality importance both in Development (robustness of justifications) and Production processes (reproducibility)
  - **Where elimination of human factor is not reasonable detailed instructions are crucial**
- **In the first instance the importance of reasonably detailed and clean instructions applies for standards like ECSS-E-ST-32-01 or SG-1-X-10**

Most challenging for future developments

- Perform comprehensive analysis of all relevant production events and of the envelope life already during the development phase
  - Early and deep analysis of production processes
  - NDI relevance and sensitivity levels
  - Further implementation of elastic-plastic methodology

→ further increase of robustness and flexibility of generic justifications (positive cost factor for the product life)