Structural Verification of ISS payloads

R. Bureo Dacal

Structures Section
ESA-ESTEC

Overview

- The structural verification of the International Space Station (ISS) Payloads is required to control the related structural failure hazard, to guarantee a safe design and to contribute to mission success.
- The control of the structural hazard is mandatory and must be reported for approval by the ESA/NASA Payload Safety Review Panel (PSRP).
- These charts are mainly focussed on ISS Payloads launched by the Space Shuttle, by Progress and by ATV

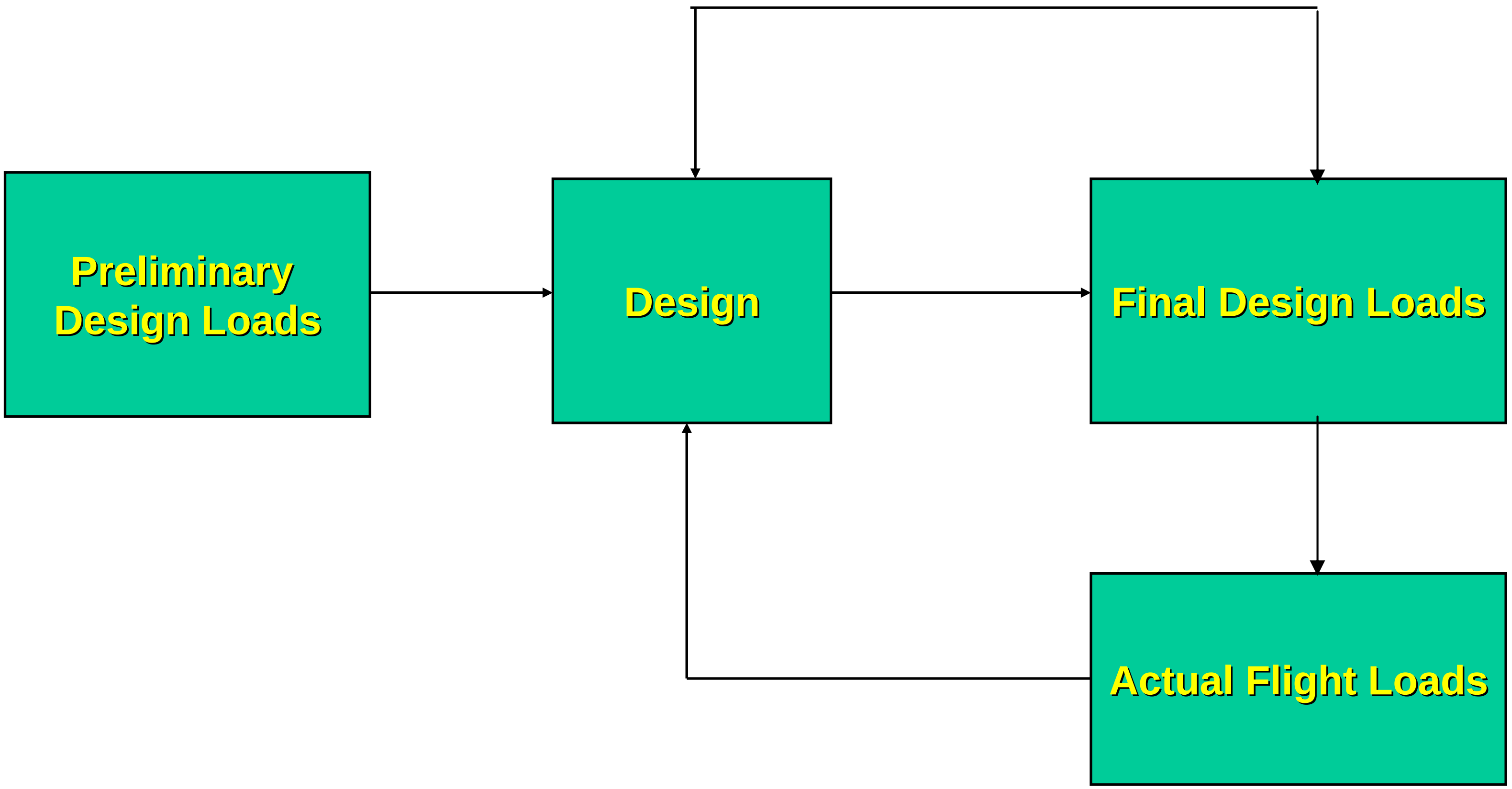
Documentation

- **NSTS 1700B + ISS Addendum** “Safety Policy and Requirements for Payloads Using the Space Transportation System and the International Space Station”
- **SSP 52005C** “Safety Critical Structures Requirements and Guidelines”
- **NSTS 14046E** “Payloads Verification Requirements”
- **NSTS 37329B** “Structural Integration Analyses Responsibility Definition for Space Shuttle Vehicle and Cargo Element Developers”
- **ECSS-Q-70-36A** “Space Product Assurance – Material Selection for Controlling Stress Corrosion Cracking”
- **MSFC-STD-3029** “Guidelines for the Selection of Metallic Materials for SCC Resistance”
- **P32928-103-2001** “Requirements for International Partners Cargoes transported on Russian Progress and Soyuz Vehicles”
- **OPS-IDD-0200** “ATV IDD”

Definitions

- **Safety Critical Structure**: All structural elements including associated interfaces, fasteners, and welds in the payload component primary load path, including pressure systems, uncontained glass, rotating machinery, mechanical stops, and containment devices.
- **Primary Load Path**: The primary load path is defined as the collection of structural elements which transfer load from one part of a structure to another. Elements in the primary load path experience loading in excess of that created by their own mass.
- **Payload Design** : Collection of data consisting of drawings, parts, materials and processes information that can be used to manufacture and assemble a payload.
- **Payload Verification** : Collection of analytical and testing activities performed to verify the adequacy of the payload w.r.t. safety and mission success. The adequacy is verified against the applicable requirements.
- **Design Limit loads** : Loads use to design the payload and that are not expected to be exceeded during the whole payload life.

Structural Verification Process



Structural Verification Process (cont'd)

- The Payload Developer must produce at PDR time a Structural Verification Plan (SVP) that includes the detailed definition of the structural design, the loads to be considered for the verification, the model philosophy (proto-flight or prototype) and all the testing the different hardware will undertake.
- The SVP must be submitted for approval to the ESA (Progress and ATV payloads) or NASA (STS payloads) bodies supporting the PSRP. In the case of ESA, to the Structures Section (TEC-MSS) and in the NASA case to the so called Structures Working Group.
- The structural verification of ISS payloads is performed by a combination of analyses and tests. In most cases, the structural verification is accomplished by analytical means based on tests are performed to validate the models used in the analytical verification.
- Tests (mainly random and shock) are performed to verify mission success.

Structural Verification Process (cont’d)

- A detailed finite element model of the payload is normally built and is used for analytical verification. The model must be checked for mathematical correctness and, at the final phase of the verification process, is validated by dynamic (either resonance search of modal survey) and/or static tests of either flight or flight representative hardware.
- Typical analyses run are the following:
  - Modal (to check modes and frequencies)
  - Static, thermo-elastic (to derive forces, stresses, displacements)
  - Dynamic (either transient or frequency response, whenever time or frequency consistent results are needed to decrease conservatism)
  - Multi-body dynamics for special cases
  - Hand or spreadsheet calculations for post-processing and derivation of MOS’s

Structural Verification Process (cont'd)

- For some payloads the validated detailed physical payload finite element model is further reduced using the Craig-Bampton technique into a mixed modal/physical model. Output Transformation Matrices (OTM's) are derived for the recovery of major outputs (forces, accelerations, displacements).
- The reduced C-B model and the OTM's are delivered by the Payload Developer to the Cargo Integrator for the performance of the STS mission specific Verification Coupled Loads Analysis (VCLA).
- The results of the VCLA, obtained by the OTM's recoveries, are compared to the design values. If every comparison is positive, the payload is certified for flight.
- The process described above is, in general, not required for payloads launched in Progress or ATV.

Loads

- Assembly and Installation
- Testing (sine, random, shock, pressure)
- Ground Handling & Transportation
- Flight, lift-off, ascent, descent, re-entry, landing & emergency landing (inertial, transients, acoustics, random, constraints)
- ISS On orbit (ISS boost, vehicles docking)
- Crew applied (IVA & EVA)
- Pressure
- Thermal

Loads (cont'd)

- During lift-off the dominant loads are inertial, transients, acoustic and random. They must be combined following SSP 52005C rules (square root, random added once per axis). Acoustic loads are normally not relevant unless the payload has a large surface. This combination is not required for ATV payloads.
- During landing inertial, transient, shocks and thermal loads are relevant.
- Loads are defined in terms of load factors and are applied in all three axes simultaneously.
- Induced loads due to redundant attachments have a significant effect and must be considered in the preliminary design and final verification. They are normally introduced by imposing displacements at the payload interfaces.
- Pressure loads are based on MDP (Maximum Design Pressure) except if they are combined with other loads.

Materials

- Metallic materials with high resistance to stress corrosion cracking are the preferred design solution. Well known Aluminium alloys for structural parts and stainless steel fasteners is a typical combination. Avoid the use of fasteners made of titanium alloys and, in general, avoid the use of titanium alloys in applications where sustained load is required.
- Well established material properties (A, B or S values) must be used in the verification. They are available (e.g. MIL-HDBK-5) for most metallic materials used.
- Composite materials may be used although their verification is rather complex. Try to avoid them unless frequency or stability requirements make their use mandatory.

Materials (cont'd)

- The strength of composite structures must be derived statistically based on samples tests representative of the specific lay-out and configuration. Also, the flight unit parts must be proof tested. This applies as well to inserts. Note : A sandwich panel made up of aluminium honeycomb and aluminium faces is a composite structure.
- Composite end of life properties and creep behaviour must be derived from dedicated tests if the payload is to be brought back in the STS.
- Also, adhesive properties must be derived at maximum operational temperature by means of dedicated tests.

Requirements

- Frequency at launch configuration above a minimum value (typical 25 up to 35 Hz) to avoid increase of loads. This requirement may be waived if time consistent system level analyses show no impact of lower frequency on design limit loads.
- Static & Dynamic Envelope within established values to avoid collisions.
- Positive Margins of Safety for all load cases and possible load combinations. The definition of Margin of Safety is :

  MOS = [Pallowable/(SF*Pdesign] -1>0,

  where SF is the applicable Safety Factor
- Fatigue life

Safety Factors

- Safety Factors for metallic structures :
  - 1.25 to yield, 2.0 to ultimate (STS and ISS, analysis only)
  - 1.0 to yield and 1.4 to ultimate (STS, analysis and static test)
  - 1.1 to yield and 1.5 to ultimate (ISS, analysis and static test)
- Safety Factors for composite structures :
  - 1.4 to ultimate (STS, non discontinuity)
  - 2.0 to ultimate (STS & ISS, discontinuity)
  - 1.5 to ultimate (ISS, non discontinuity)
- Safety Factors for glass & ceramics :
  - 3.0 to ultimate (analysis and static test)
  - 5.0 to ultimate (analysis)
- Safety Factors for bonds :
  - 2.0 to ultimate (analysis and static test)

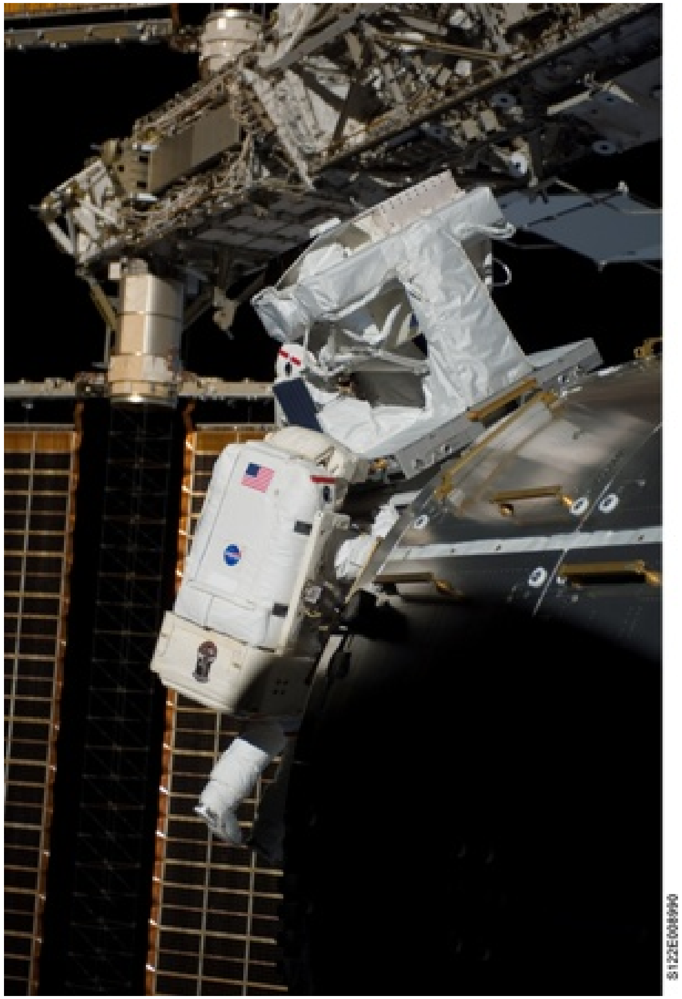
Safety Critical Fasteners

- Safety Critical Fasteners must be procured to aerospace standards. Certificates of manufacturer plus batch traceability and batch incoming tests reports must be provided.
- Fasteners must show two verifiable locking provisions. One is provided by the preload, the second must be a locking nut, insert or other mechanical means (no loctite or adhesive).
- Fastener installation must be performed by first measuring the running torque and then applying the sum of the measured running torque and the design seating torque.
- Verification of fastener during tightening is often the worst case and many times it is not checked.

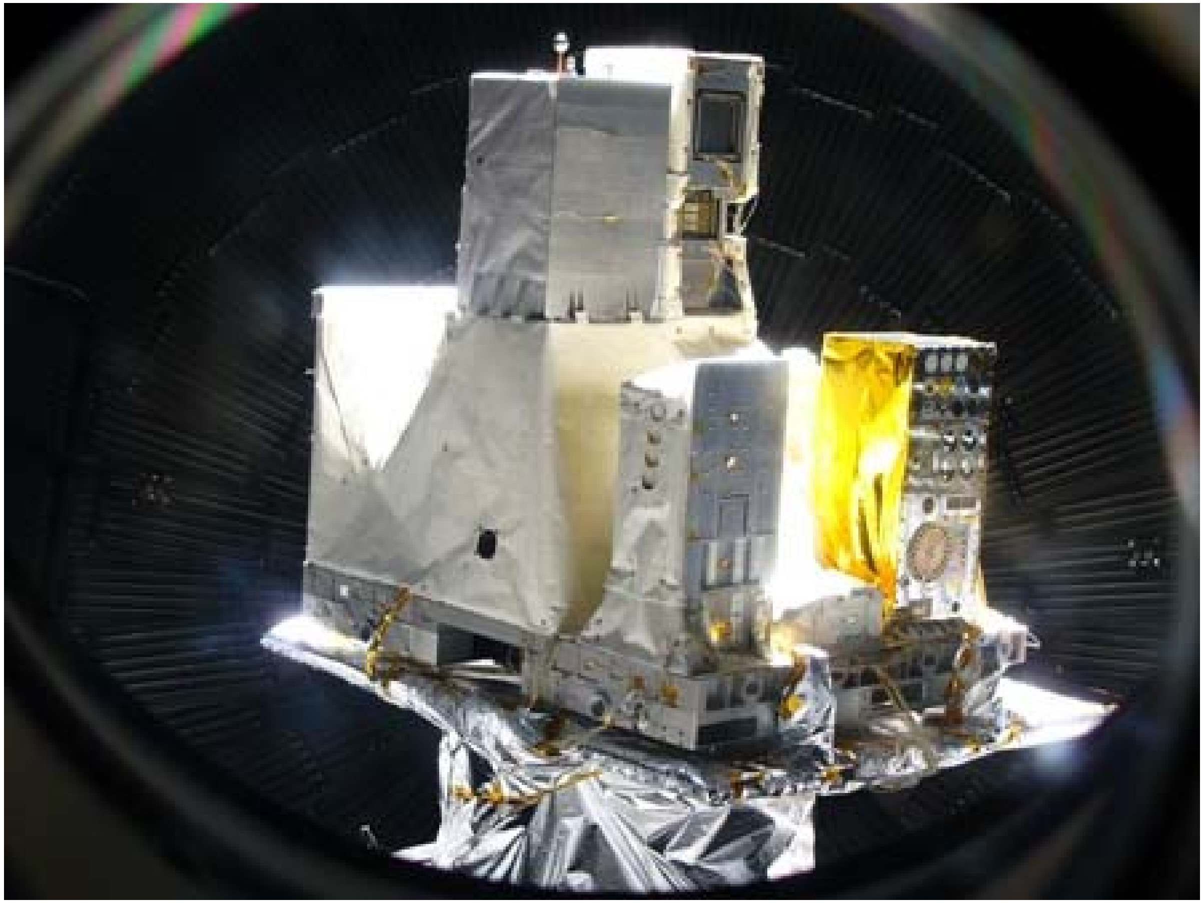
Hazard Reports

- Structural failure is normally classified as catastrophic
- A unique hazard report must be issued when the payload is hard-mounted for launch and landing and when it is hard-mounted in the ISS (e.g. in the aisle) and is accessible to the crew.
- The standard hazard report applies when the payload is soft stowed for launch and landing and is not hard-mounted to the ISS.

SOLAR

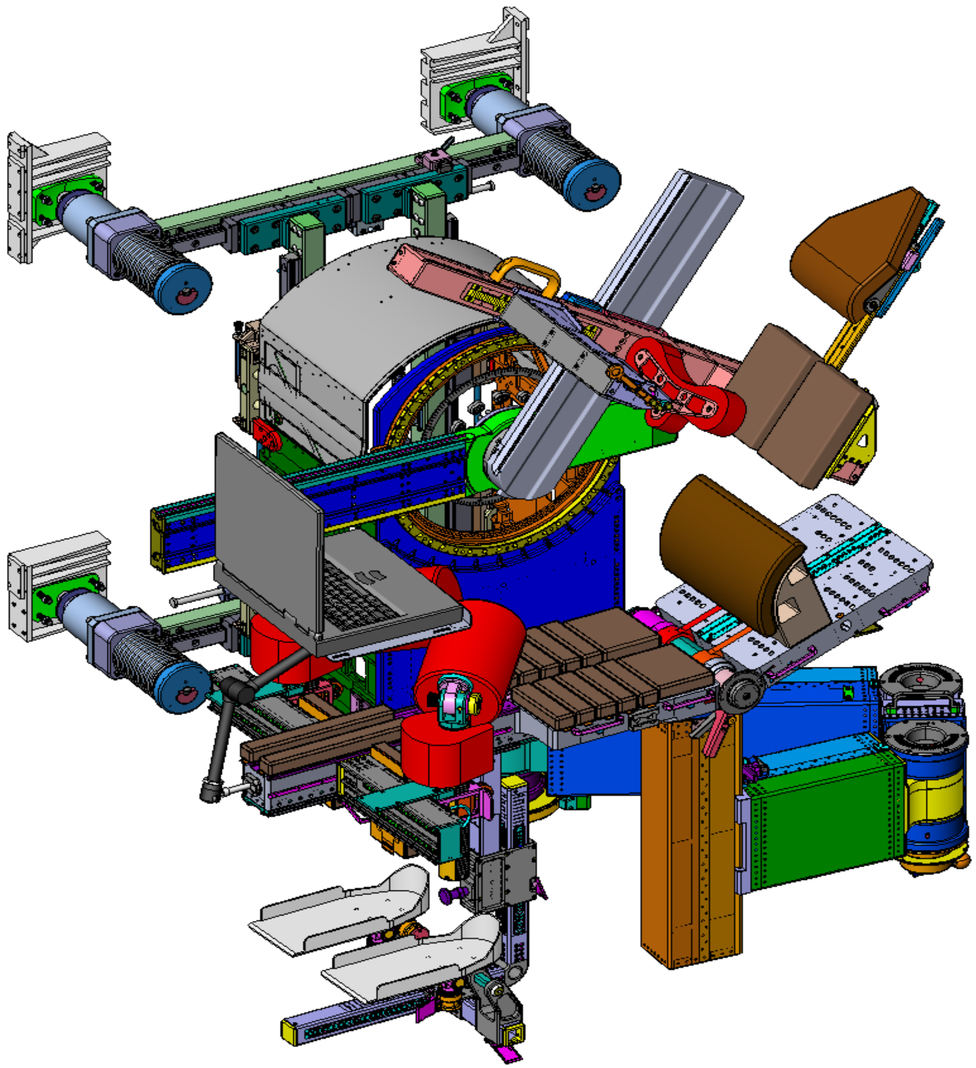


EUTEF



FWED

MARES



COLUMBUS RACKS