Characterization tests of structural joints behavior during re-entry

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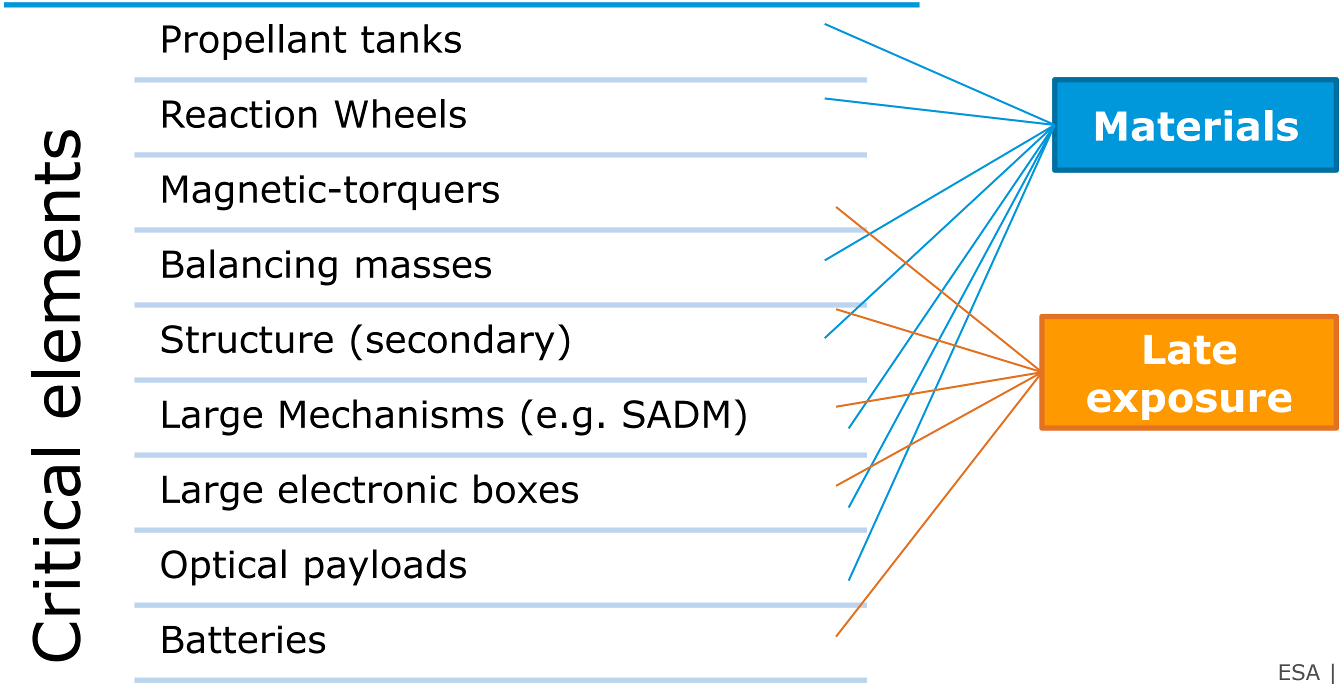
Design for Demise Critical elements

- Spacecraft oriented re-entry simulation tools have shown that an early break-up of the main structure improves the overall spacecraft demise.



Critical elements

- Propellant tanks
- Reaction Wheels
- Magnetic-torquers
- Balancing masses
- Structure (secondary)
- Large Mechanisms (e.g. SADM)
- Large electronic boxes
- Optical payloads
- Batteries

Materials

Late exposure

Design for early break-up

- Spacecraft are design to survive harsh launch environment and years of exposure to space environment.
- The break-up during reentry is an extremely complex process and difficult to characterize.
- Capability to mimic reentry conditions on ground is limited.
- Reentry observations are very scarce and technically challenging.
  - Flight observations need to know reentry area (controlled reentry)
  - On-board observations need to transmit the observations before splash-down

Tests in state-of-the-art facilities are needed to characterize behavior of structural joint technologies during reentry.

Representative Forces

Forces are Relatively Small

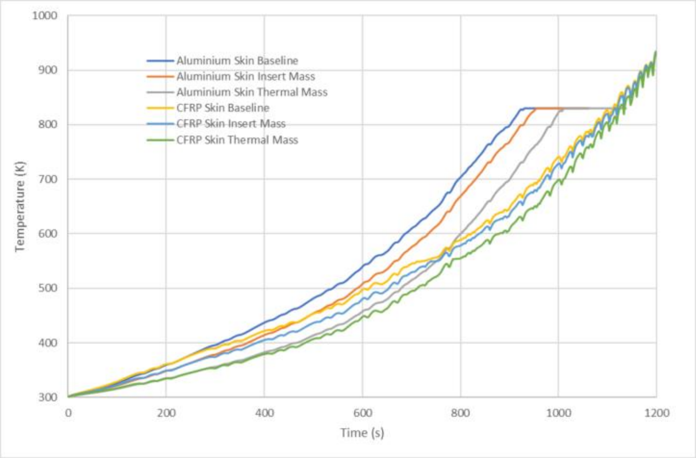
- Altitudes above 80km of interest
- Tensile forces due to centrifugal force at expected spin rates
- Impact of spin is higher at higher altitude
- Shear forces can also be significant

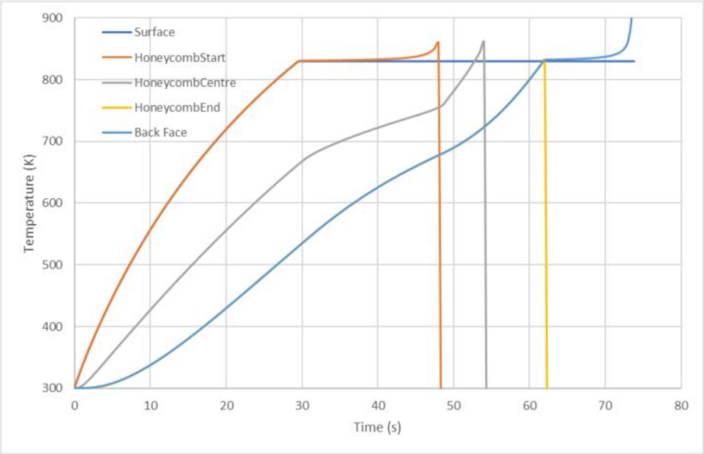
Altitude (km)	Longitudinal Force (N)	Faster Spin Force (N)	Shear Force (N)
80	20	25	40
85	10	25	20
90	4	25	8

Representative Heat Fluxes

Altitude (km)	Surface Area Average Heat Flux (kW/m²)	Edge Region Average Heat Flux (kW/m²)
80	80	100
85	60	75
90	40	50

- Sandwich Panel Analysis
  - Uncontrolled re-entry trajectory
    - Sandwich close to isothermal (slow heat soak)
  - Comparison with constant 50kW/m² condition
    - Larger temperature gradients; different behaviour?





Phenomenological Testing

The phenomenon of thermo-mechanical fragmentation has not been systematically studied before

This phenomenon needs to be explored in addition to joint characterisation

Some pertinent questions are:

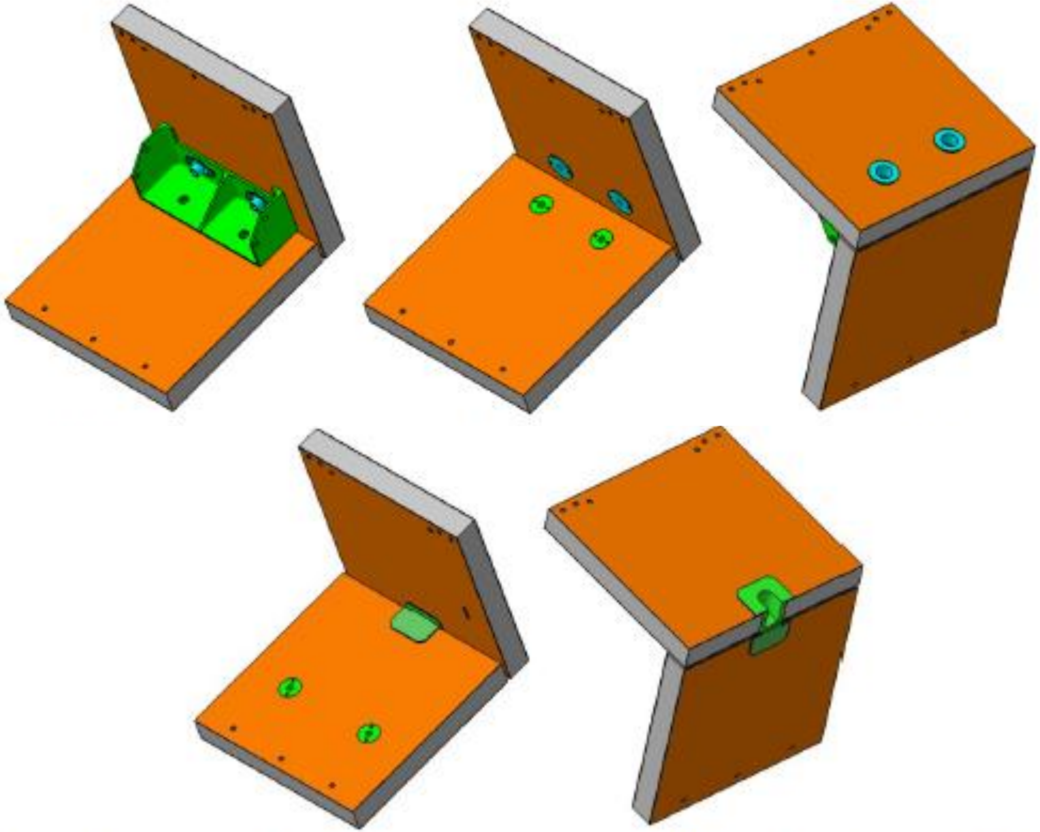
  - What drives fragmentation e.g. simple melt, joint failure, panel failure?
  - Is the same failure phenomena seen across a range of conditions (forces / fluxes)?

Guides how best to characterise joints and provides insight into promising re-design to promote fragmentation

Phenomenological testing is pursued at two facilities

  - Static facility (AAC): greater flexibility associated with application of low fluxes over long durations
  - Plasma wind tunnel (DLR-K): includes flow phenomena and aero-chemistry

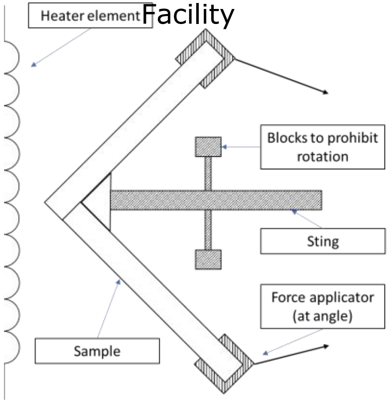
Types of joints tested



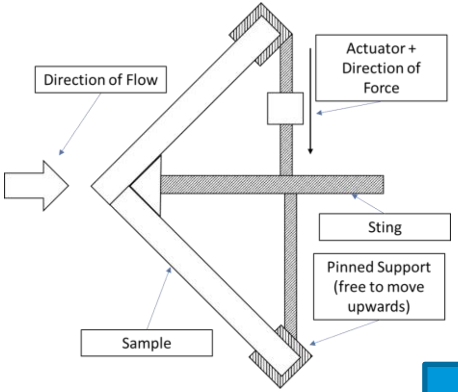
Phenomenological Test Setup

- Static Facility - Initial forces applied at angle to provide both shear and tensile components through insert (at both initial position and at end position)
- Wind tunnel - No blocks to prohibit bending – bending limited by actuator movement range
- Edge insert - Connected to standard insert as cleat not available for edge insert configuration
- Backing plate used to provide support – insulated with ceramic paper

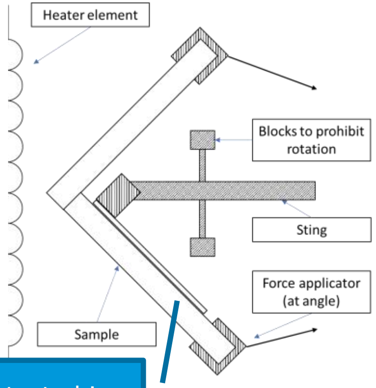
Static Facility



Wind Tunnel



Edge Insert



Also tested in wind tunnel but not shown here

Phenomenological Test Setup

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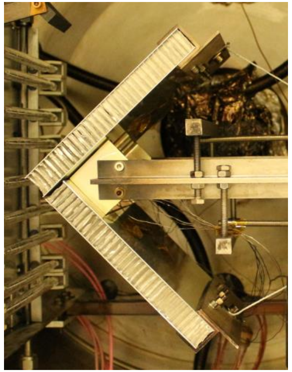
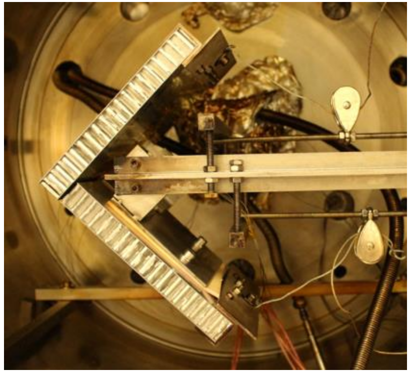
Static
Facility



Wind Tunnel

Edge Insert



Static Phenomenology

First key observations

- Differences in behavior on trajectory and constant flux conditions
- Insert failure before panel failure has only been observed under a gradual heat soak (consistent with CleanSat building block exploratory work)
- Trajectory flux closer to isothermal; long time at 'high' temperature for potting material failure

Static Phenomenology

Further effects:

- Panel failure before insert failure observed with increased force
- Surface insert pull out (very different behavior) observed with reduced force
    - Force levels required affected by face-sheet material (supported by Cleansat building block observations)
- Balance between force and heat soak is important in determining failure mode
- Dynamic motion acts to potentially inhibit the insert removal
    - There is evidence of insert pull-out, but not as clear as static force tests
- Earlier outgassing with CFRP facesheets; faster temperature rises in TC traces
    - Heating to interior through (4ply) CFRP facesheets is greater than through Al
    - Lower conductivity of thin sheet offset by lower thermal inertia (mass, Cp)
    - Was not expected in pre-campaign, but is confirmed in numerical simulations
- Substantially more empirical evidence needed to generalize behavior

Plasma Wind Tunnel Phenomenology

- Different phenomenology is observed due to flow effects
  - Numerical rebuilds suggests greater flux gradient along sample (original shape)
  - Edge effects are clearly important; damage is less evident in center
  - Outgassing is immediate – no time delay
  - Melt at leading edge; movement of actuator at point that the panel can bend around the cleat
  - Test times are noticeably smaller in the wind tunnel
- Do these effects change preliminary conclusions from the static test (trajectory flux) observations?
  - It is still an open point concerning whether the static-facility thermal effects occur before the flow effects (as seen in the wind tunnel) become important.

Summary

Initial indications are that joint failure could be seen for “trajectory fluxes” i.e. long time at elevated temperature (characteristic of uncontrolled entry)

    More empirical testing required to confirm the generality of this conclusion

Panel failure seen at higher fluxes and forces (more applicable to controlled re-entry?)

Local melting can occur around regions of high aerothermal flux (sharp edges, as seen in the dynamic facility)

    Edge effects are more prevalent on subscale samples

Multiple failure modes could be expected

Demisable joints should be designed such that joint failure is anticipated well in advance of panel failure and/or melt-driven fragmentation

    Potting material takes a long time to weaken and char (charring is an endothermic process)

Spacecraft design considerations

- Passive solutions actuated by the reentry environment preferred.
- Panel failure interrupts the transfer of mechanical loads to the joints and does not guarantee the internal equipment early exposure nor predictability.
  - This can be particularly relevant in the case of panels with CFRP face-sheets for which there are higher uncertainties.
- Designing joints to thermally fail rather than panels has at least two benefits, leads potentially to an earlier and more verifiable breakup
- Enhancement of the inserts failure through redesign of inserts and potting materials with a different and well characterized behavior at high temperatures.
- Once joints fail, need to ensure separation in a low force dynamic environment
  - Some motorization may be needed to ensure the separation of the panel.

Next steps

- Trade-off the different concepts being proposed for the design of a demisable joint
- Design and Breadboard of preferred solutions for structural joints designed for demise
- Breadboard functional tests (structural)
- Breadboar reentry test in static and dynamic facilities to verify improvement of break-up/demise.
- Definition of full development and qualification roadmap.

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