OHB System AG
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ESTEC

Institute of Aerodynamics and Flow Technology
INVENT
Belstead

SPACE SYSTEMS

Methodology and results of demisability testing for state-of-the-art structural joining technologies

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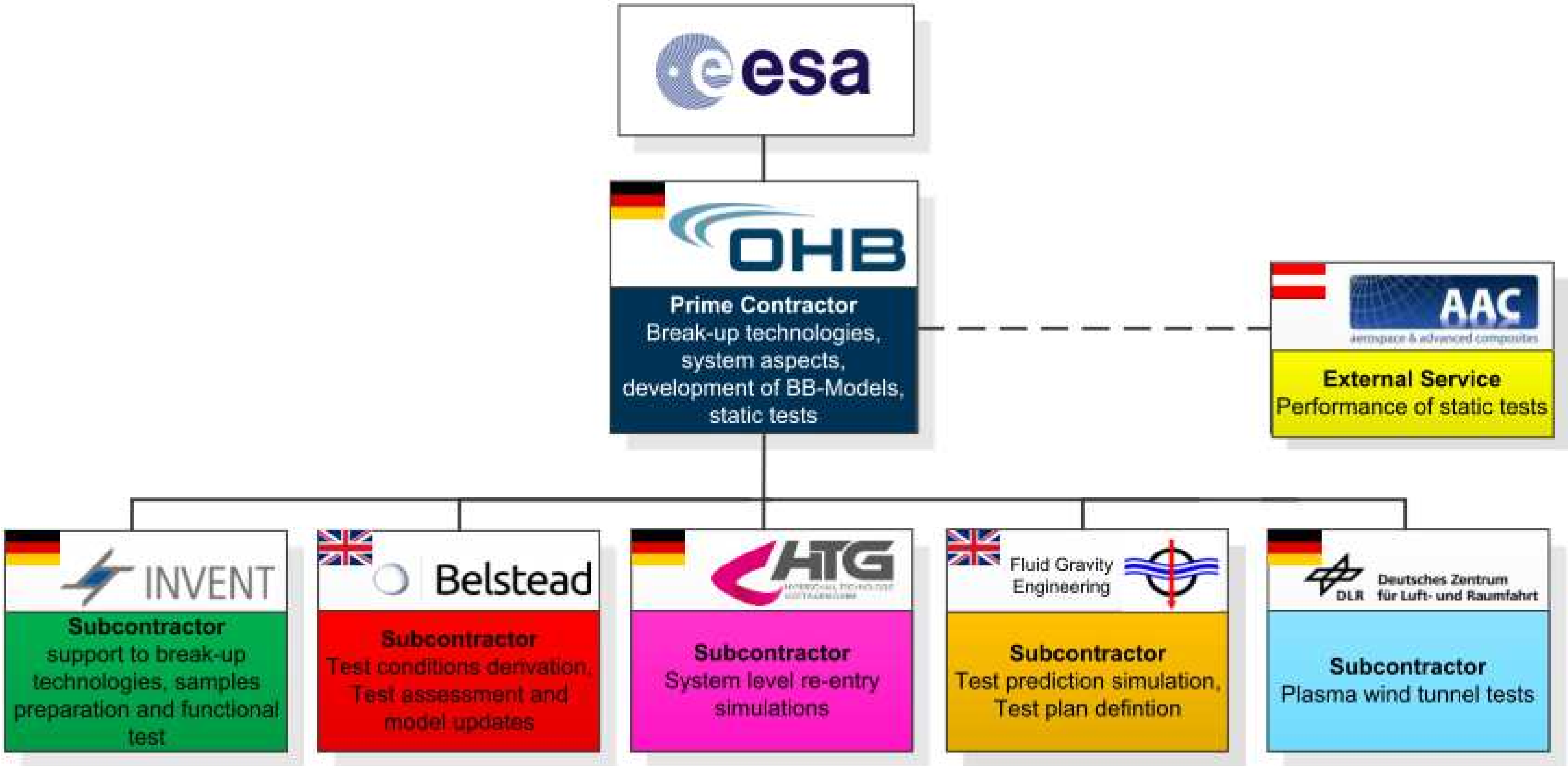
Objectives of the Study

The objectives of the activity are

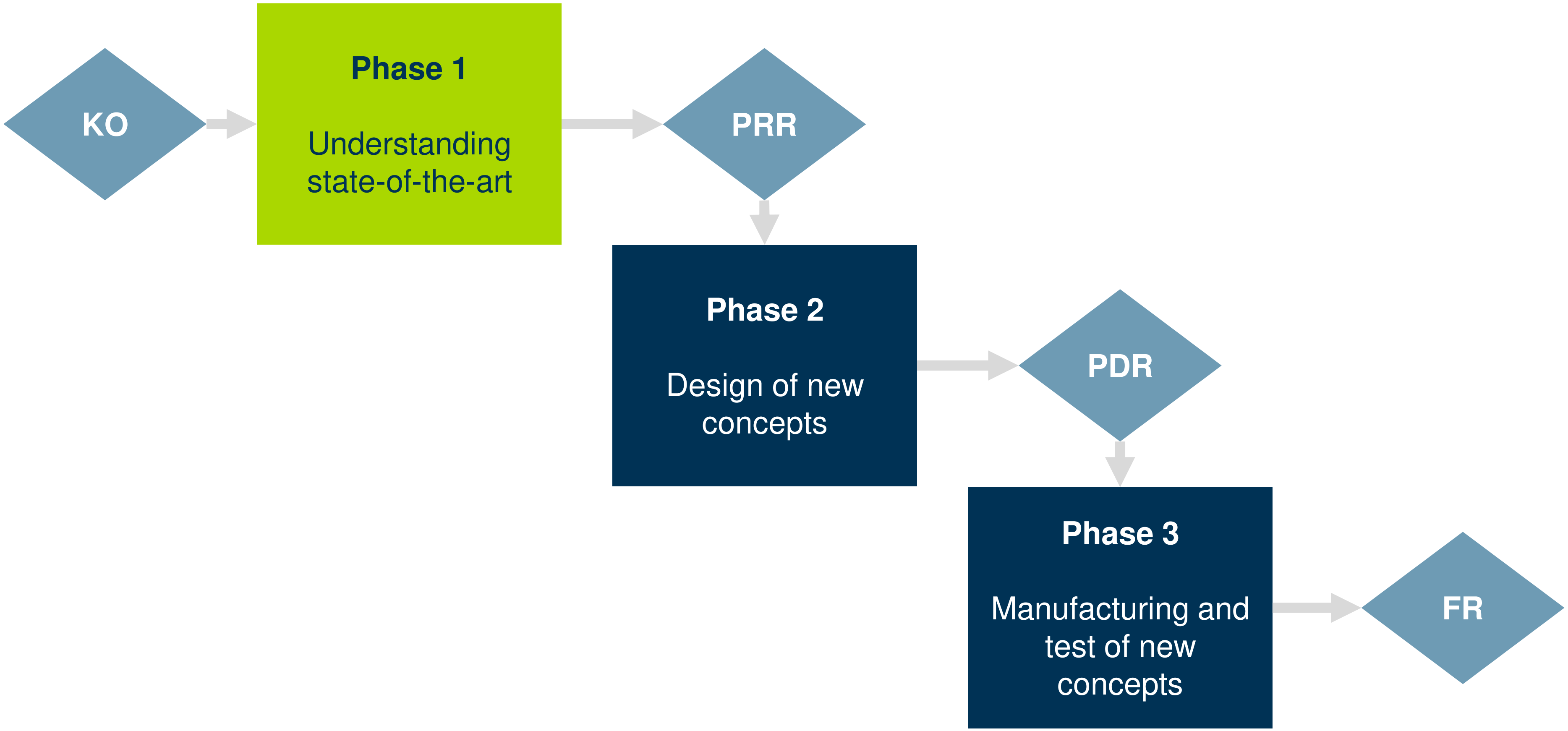
- To define feasible design concepts to achieve a spacecraft structure break-up or structure opening at an altitude above ist natural break-up altitude and
- To demonstrate the feasibility of selected technologies by breadboard development and testing.

- Focus is set on technologies to open and/or release external structural elements and spacecraft modules (e.g. payloads and large appendages) to increase the overall spacecraft demisability

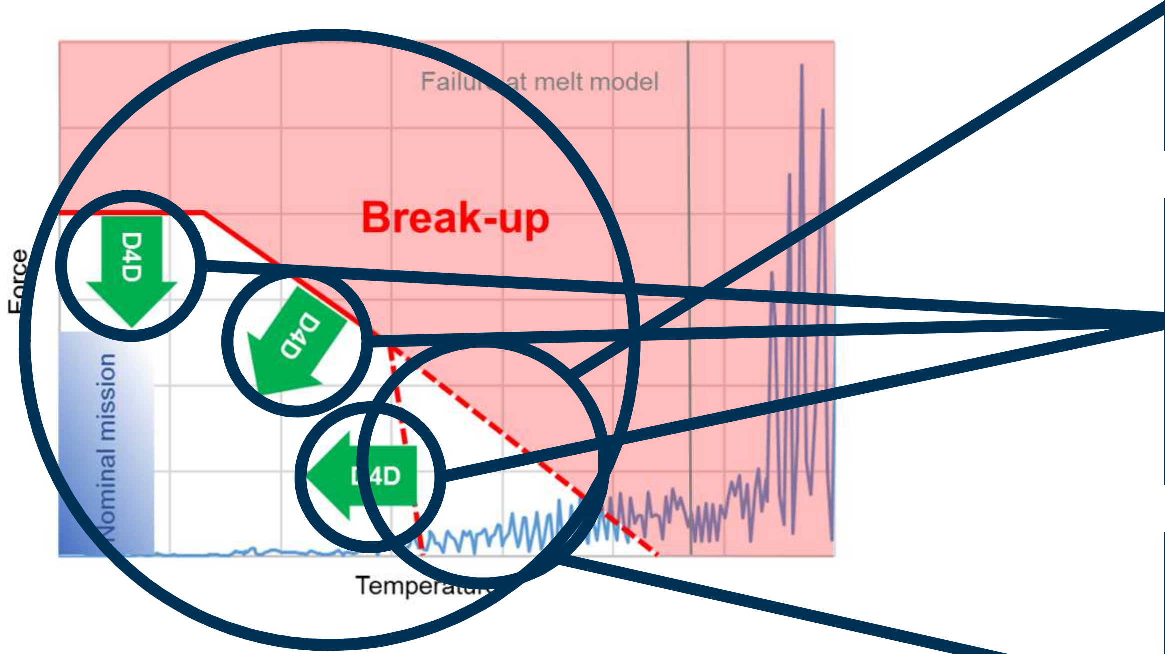
The team to bring D4D to breadboard level



Study Overview



Technologies to increase a satellite‘s break-up altitude



Phase 1

Understanding state-of-the-art

Phase 2

Design of new concepts

Phase 3

Manufacturing and test of new concepts

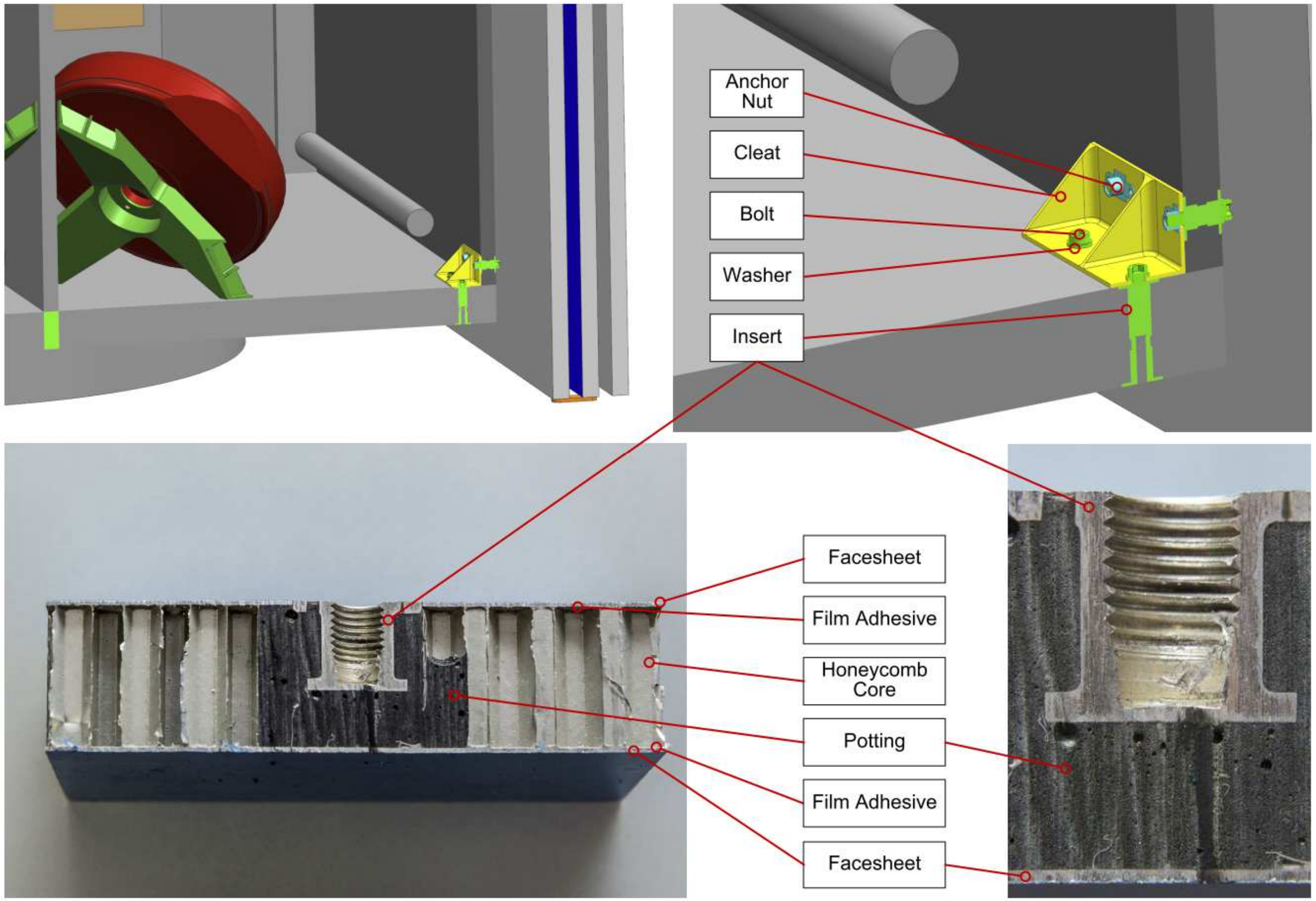
Identification of existing Joining Technologies

“Joining technologies are components, parts or materials which connect structural elements or equipment of the spacecraft.”

- **Joining Technologies**
  - **Mechanical Joining**
    - Bolted Joint
      - Bolt
      - Washer
      - Cleat
      - Helicoil
      - Insert
      - Anchor Nut
      - Potting Compound
    - Rivet Joint
    - Wired / Tethered Joint
    - Adhesive / Bonded Joint
      - Tertiary Structure
      - Unit Attachment
      - Sandwich Constructions
      - Potting Compound
  - **Thermal Joining**
    - Welded Joint
    - Brazed Joint
    - Soldered Joint

Definitions	
Cleat	A joint that is used to connect the panels of a spacecraft.
Bracket	A joint that is used to mount units and electronic boxes onto the panel.

Relevant Joining Technologies for D4D Breadboarding



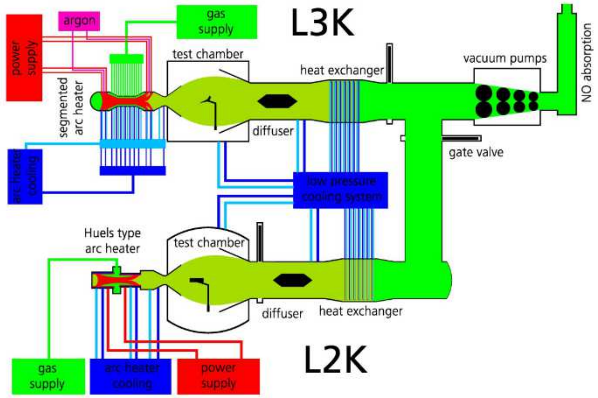
Test Plan and Conditions

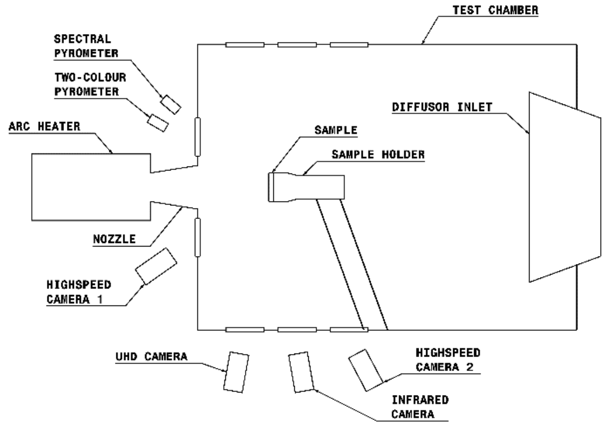
- Derived to be representative and to drive a better understanding of potential re-entry scenarios
  - A baseline was established using a generic spacecraft with lengths of 1-3 m, aspect ratio of 1-3 and ballistic coefficients between 80 and 250 kg/m^2
- Heat flux (three defined values of the: “trajectory heat flux”, **50** and 100 kWm^{-2}).
- Mechanical Load (three defined values of static loading: 5, **20** and 50N; dynamic loading at 0.5 and 1.0 Hz; shear and tensile forces).
- Connection type (**Cleat & Spool** and Edge inserts).
- Facesheet material and thickness (Aluminium and CFRP (CFRP at two thicknesses: 4 and 8 ply)).

(Baselines in bold)

Test Facilities

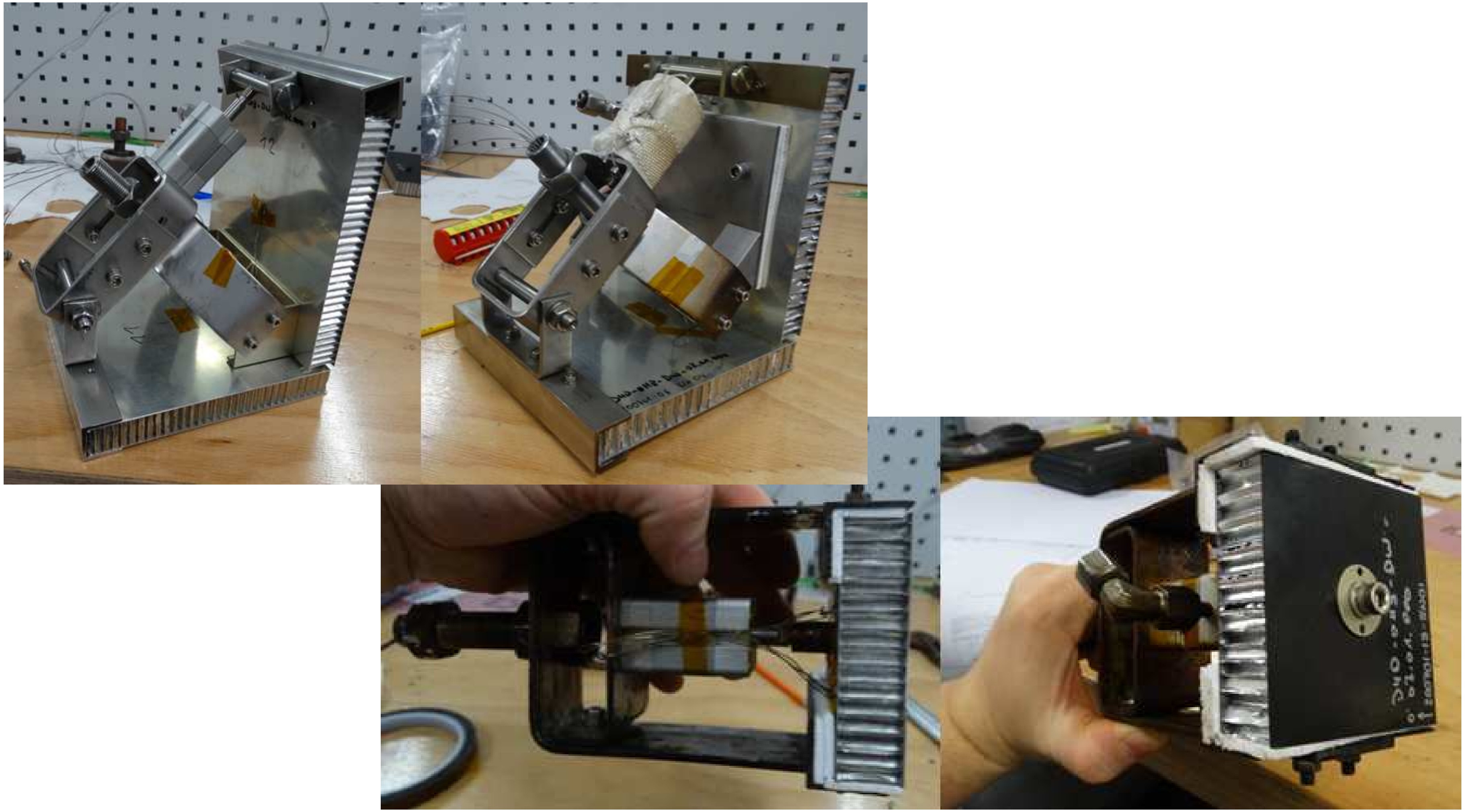
- AAC´s Re-Entry Chamber is a multi-purpose thermal vacuum chamber specifically designed for testing materials and small components under re-entry relevant heat fluxes





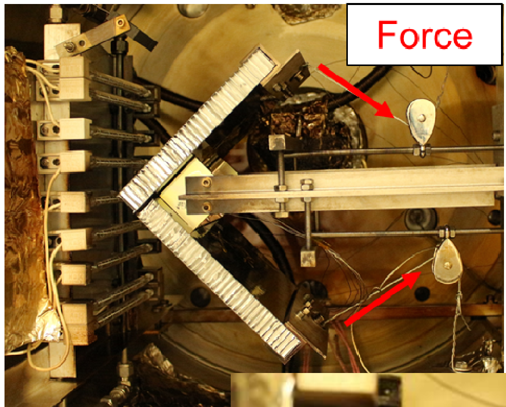
- L2K of the German Aerospace Center (DLR) in Cologne. The L2K is a blow down wind tunnel facility with a free stream test section. It is one of the two legs of the LBK facilities

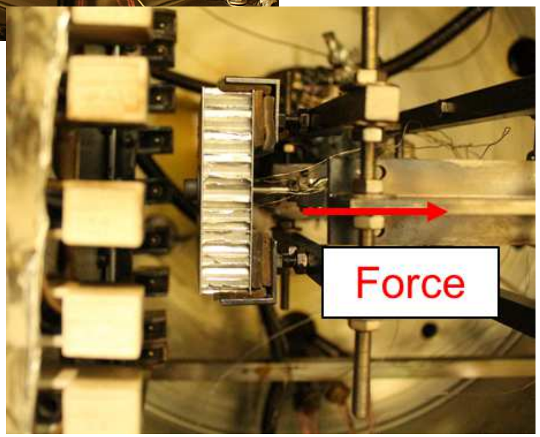
Test Samples



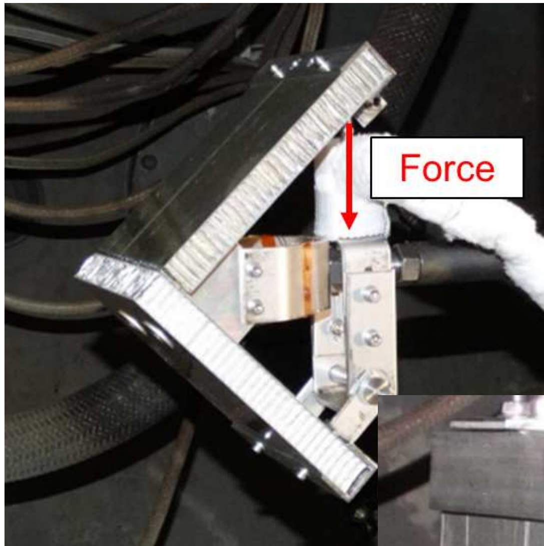
Test Setups

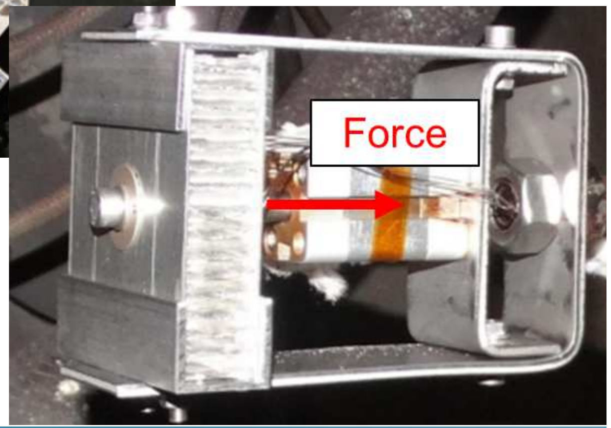
Static Facility (phenomenological and characterisation) Setups:





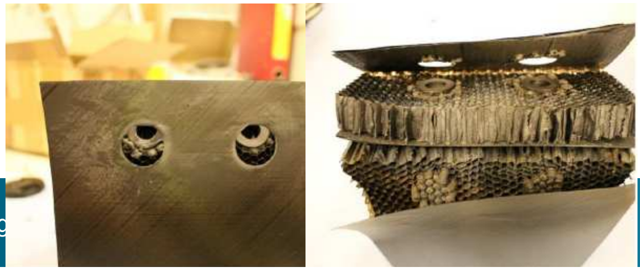
Wind Tunnel Facility (phenomenological and characterisation) Setups:





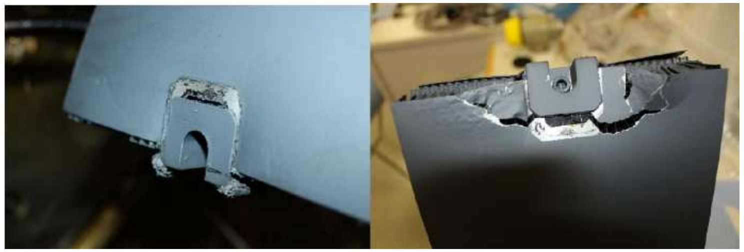
Results – Static Test Chamber

- The longer heat soak in the trajectory flux case allows the bonding material the time to denature (contrast to constant heat flux)
- For the edge inserts, some insert movement is seen in all cases
- Higher loading (50 N), more likely sandwich failure (contrast to lower loading of 5 N)
- Higher temperature seen with CFRP facesheet samples
  - Suggests that lower mass and thermal heat capacity of CFRP sheets dominates over low conductivity for these very thin structures
- No material tearing in the CFRP samples (suggests CTE effect)



Insert pull-out in traj case

Sandwich failure in constant flux



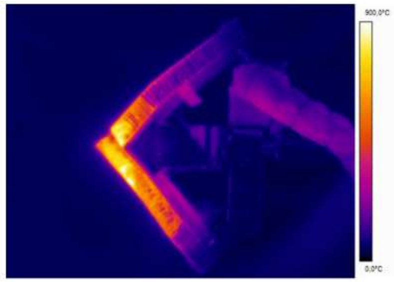
Results – Wind Tunnel Facility (1/2)

- Differences seen in comparison to re-entry testing
  - Such as immediate visible outgassing due to high flux on the leading edge
- Edge of sample saw considerable melting of the honeycomb
- Melting of the leading edge of panels appears to inhibit facesheet removal
  - Peeling of facesheets not seen and removed by melt layer
  - Flow effects potentially hold it in place
  - Panel strength is lost much earlier than in re-entry chamber
- Once facesheet removed, honeycomb very vulnerable to heat flow

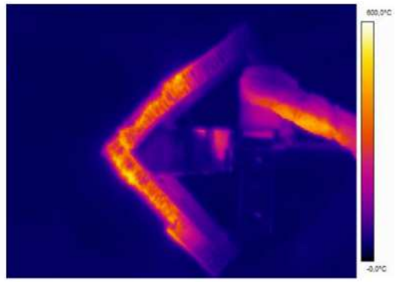
Results – Wind Tunnel Facility (2/2)

- Increased heating also seen at edges for CFRP
  - Fibres fold back as matrix material ablates
- Loose fibres at the edge of the sample also observable in IR images
  - Appear to remain attached for majority of test
- Centre demises slower than edge again
- Evidence of protection of upper panel due to overlap of lower panel
- Protection of the honeycomb by CFRP also seen
- Temperatures in the panel are higher for CFRP than with aluminium as in re-entry facility

CFRP Facesheets



Aluminium Facesheets



Discussion (1/2)

- Large amount of useful data generated for increasing understanding of initial opening of spacecraft

- Key Lessons:
  - Large difference in behaviour of the inserts and materials on an uncontrolled re-entry heat flux profile than that observed at lowest heat fluxes of plasma wind tunnel
  - Relatively steep trajectory limits the heat soak time and the inserts are unlikely to fail before the sandwich structure
  - The inserts essentially survived in all constant heat flux cases
  - For shallow trajectory, the heat soak time is sufficient to denature the potting material and fail the inserts
    - The threshold between the two cases has not been established

Discussion (2/2)

- Key Lessons (continued):
  - Thin 4 ply CFRP facesheets result in more heat penetrating to the honeycomb than standard aluminium due to low thermal inertia
  - High fluxes at leading edge in wind tunnel result in the loss of strength which means that the mechanism by which the panel fails under force is substantially different to that observed in the re-entry chamber
  - Majority of aluminium, honeycomb or facesheet, is removed in pieces rather than sheared droplets (only seen in wind tunnel)
    - Peel mechanism suggests material is close to melt
  - Further work is required to understand whether the flow behaviour which weakens the leading edge of the panels can act to reduce the force transmission through the panels such that the facesheet, panel, and insert failure mechanisms observed in the re-entry chamber might be affected.

Conclusion

- Still much to learn regarding atmospheric demise
- Broad range of phenomena and effects seen
- Understanding of demise processes greatly increased
- There are a number of failure methods which can be leveraged for earlier demise options
- Knowledge gained being fed back into selection of technologies to test in a second round

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