Characterisation of the behaviour of typical spacecraft materials exposed to re-entry environment conditions

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CSID 2017

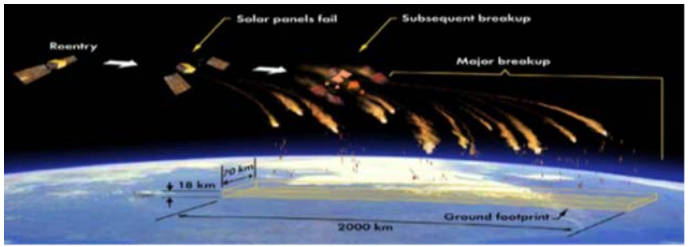
The Problem

R E E N T R Y

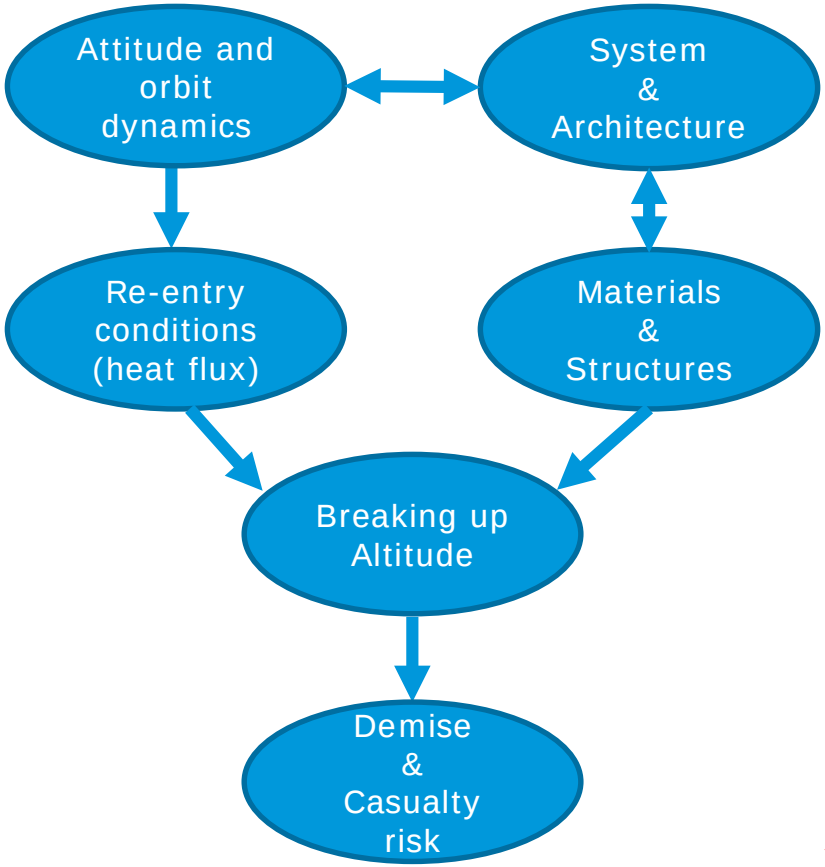
- LEO spacecraft and Launcher upper stages

- Orbital Decay at end of operating Life
- Uncontrolled re-entry in Earth Atmosphere

- Space Debris impacting ground



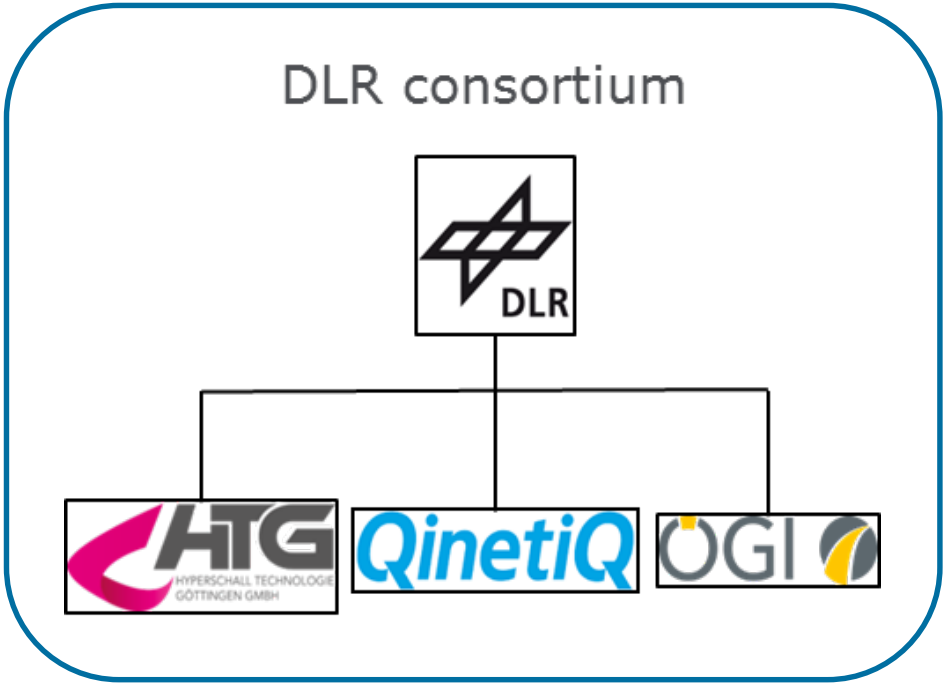
Demisability: A Multi Disciplinary Field

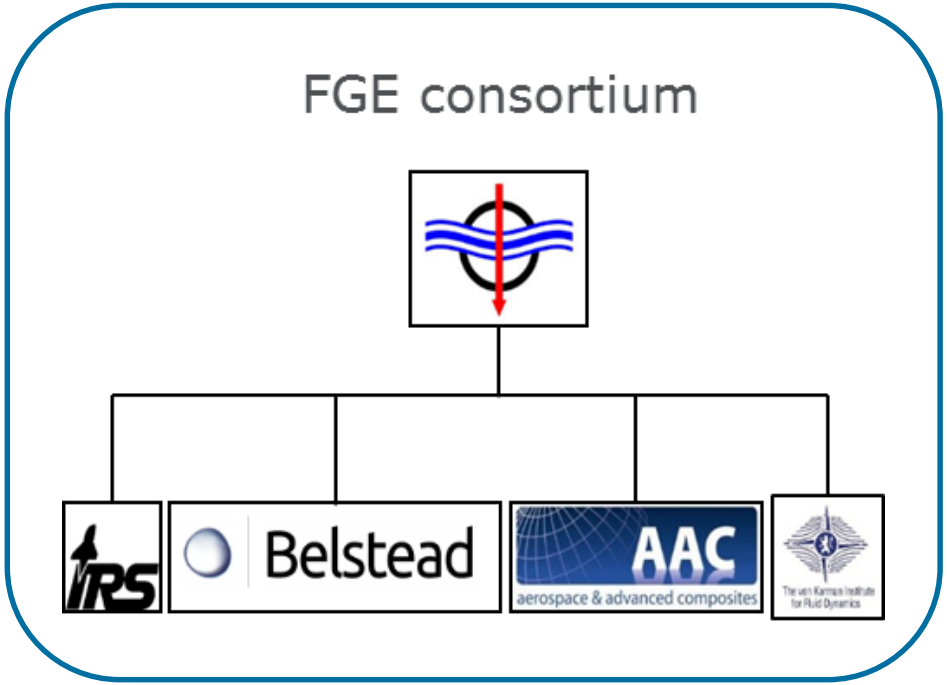


SIMULATION

ESA initiative for material characterisation

- **Two Technology Research Programme (TRP) contracts of 300Keuros each**



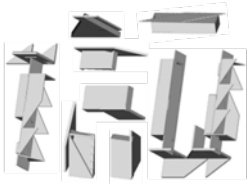


Common Spacecraft Material selection

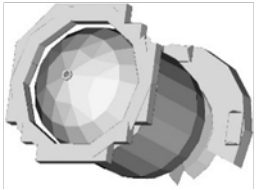
Re entered debris

Critical components from re-entry simulations

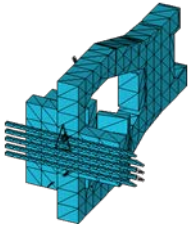
Structures (Titanium brackets)



Propellant tanks



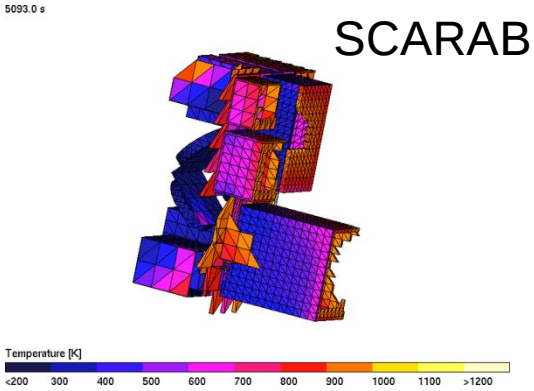
Optical payloads

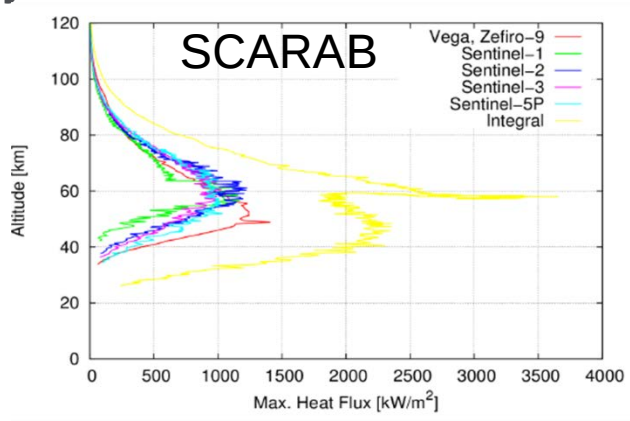


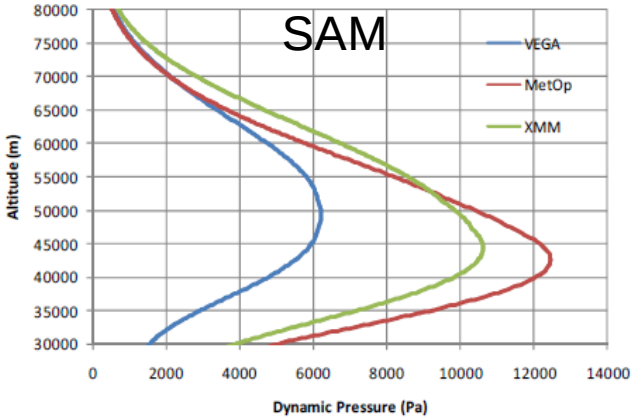
Metals	•Ti6AL4V (tested @DLR,IRS)	•316L (tested @DLR,IRS,VKI)	•Al7075 (tested @DLR,IRS)	•Al-Li 2099 (tested @IRS,VKI)	•Selective Laser Melted Ti6Al4V (tested @DLR)
Composites	•Monolithic CFRP Hexcel M55J carbon fibre/EX-1515 Cyanate ester (tested @IRS)	•Monolithic CFRP Hexcel IM7 carbon fibre /PEEk matrix			
Ceramics	• Silicon carbide				
Material combinations	• COPV structure : CFRP T1000 fibre/UF3325 epoxy matrix+Ti6Al4V(liner) (tested @DLR,	•Sandwich panel: Hexcel M55J carbon fibre/ TenCate EX-1515 cyanate ester and Al honeycomb (tested@DLR)			
Fiber Metal Laminates	• GLARE				

Test conditions and facilities selection

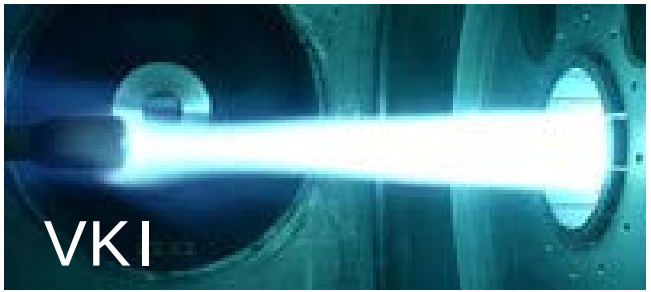
- **Simulation of re-entry events**





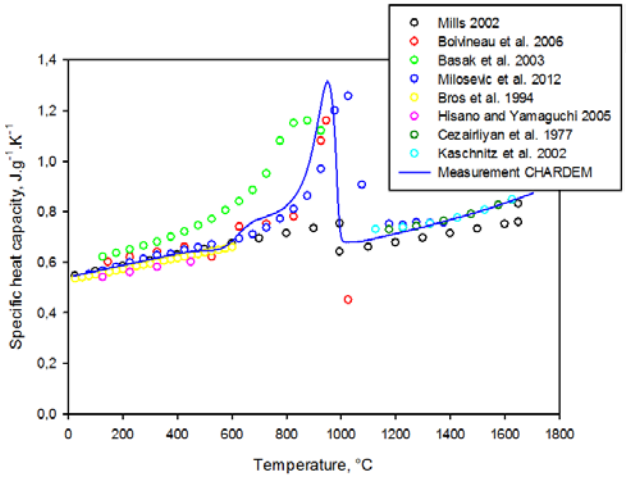


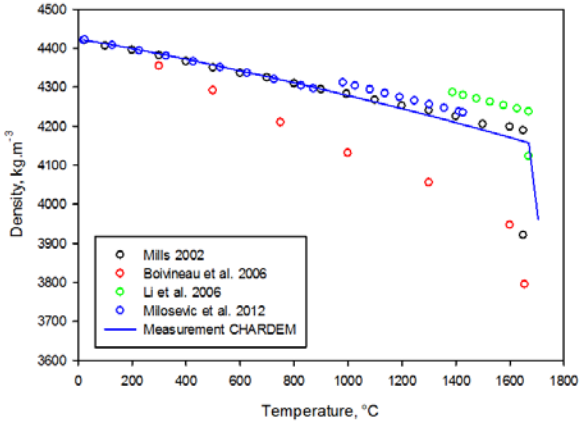
- **Facilities selection :**

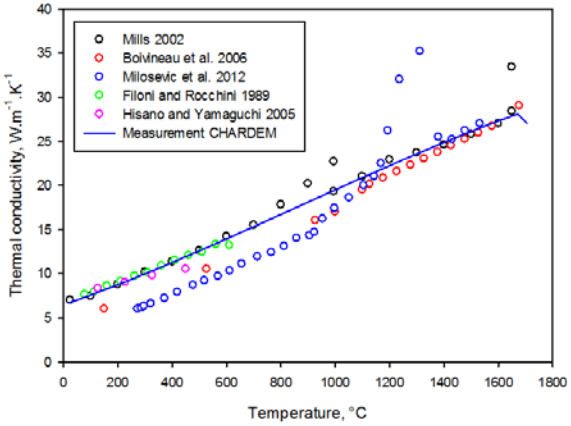


Thermophysical properties characterisation

- **Direct inputs for the re-entry simulation software**
- **Direct inputs for simulating the plasma wind tunnel tests**
- **Specific heat capacity, specific enthalpy, thermal expansion, density, thermal conductivity were measured or calculated (DSC, Pulse Heating calorimetry, DTA, LFA)**



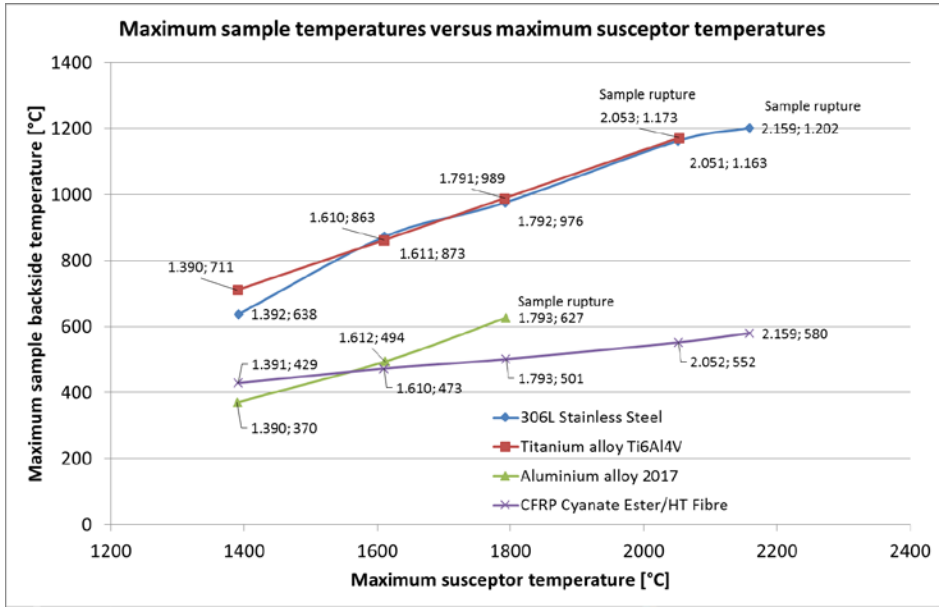




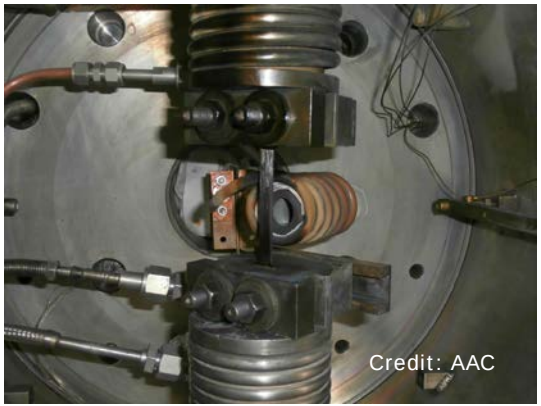
Credit: OGI

Mechanical properties characterisation

- **Direct inputs for the re-entry simulation software**

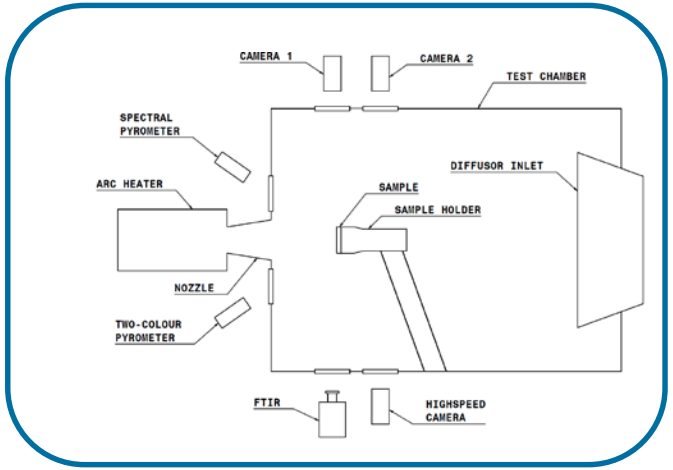


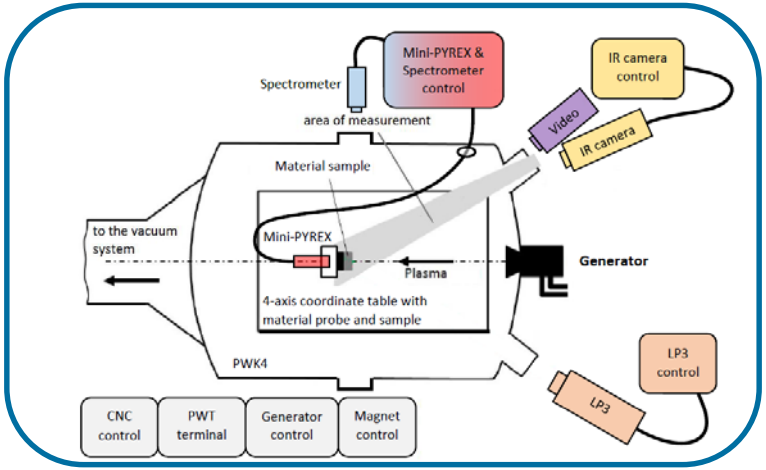
Credit: AAC

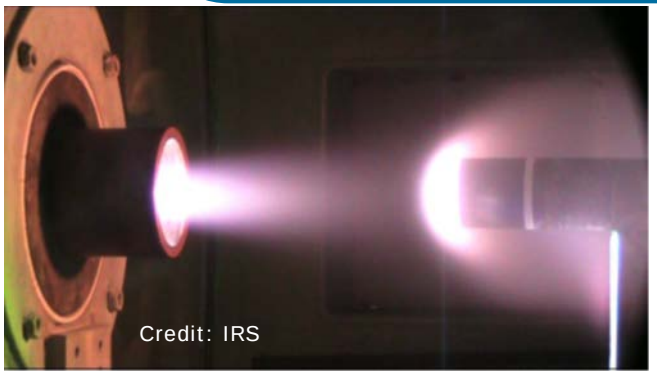


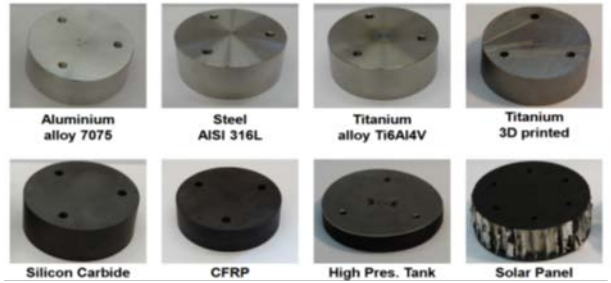
Plasma Wind Tunnel test campaign

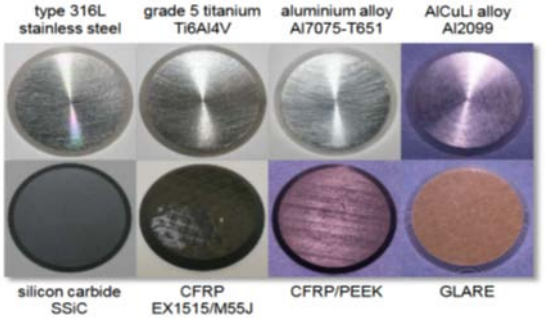
- **Test configuration**





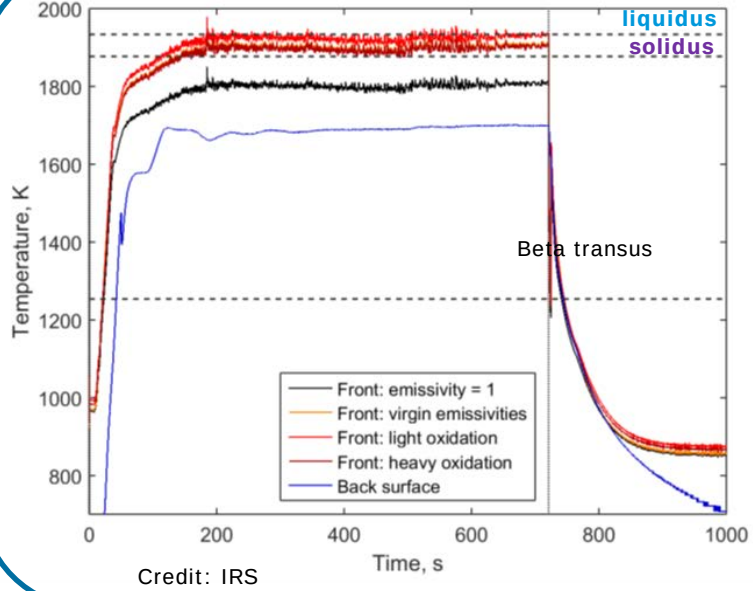






Plasma Wind Tunnel campaign

- **Ti6Al4V**

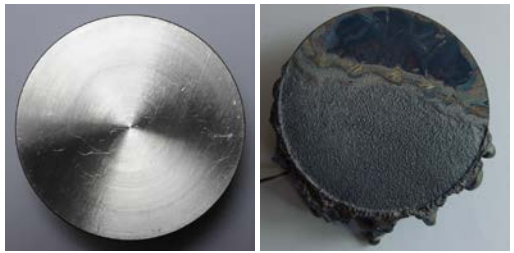


- **Steady state is reached without melting when testing at heat flux representative of uncontrolled re entry from LEO conditions (1.4MW/m²)**
- **Surface modification (oxides formation)**

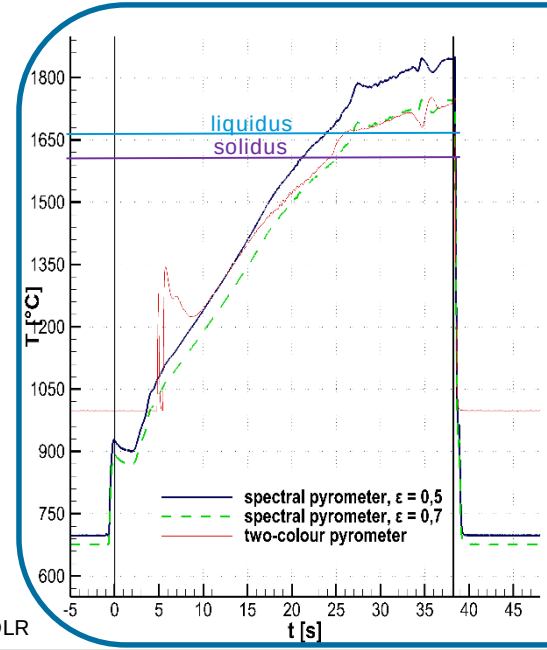
Plasma Wind Tunnel campaign

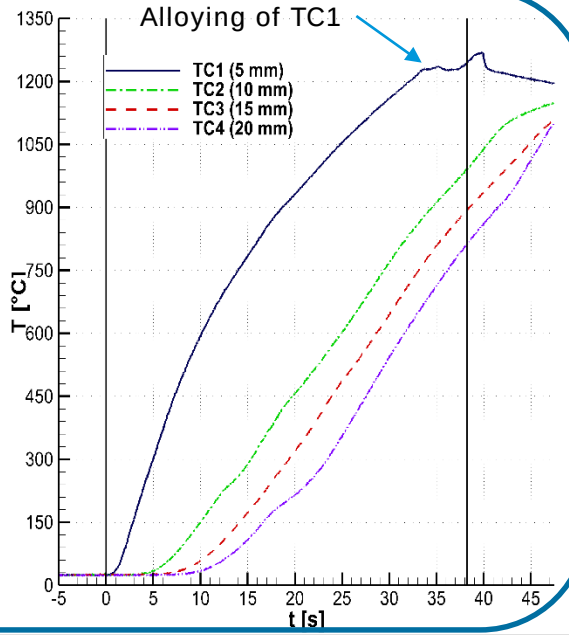
- **Ti6Al4V**

- **High eccentric re-entry conditions to observe demise mechanisms (2.3MW/m²)**



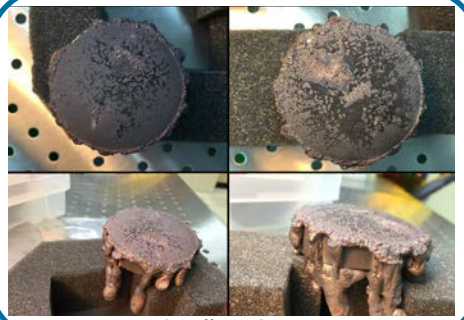
Credit: DLR

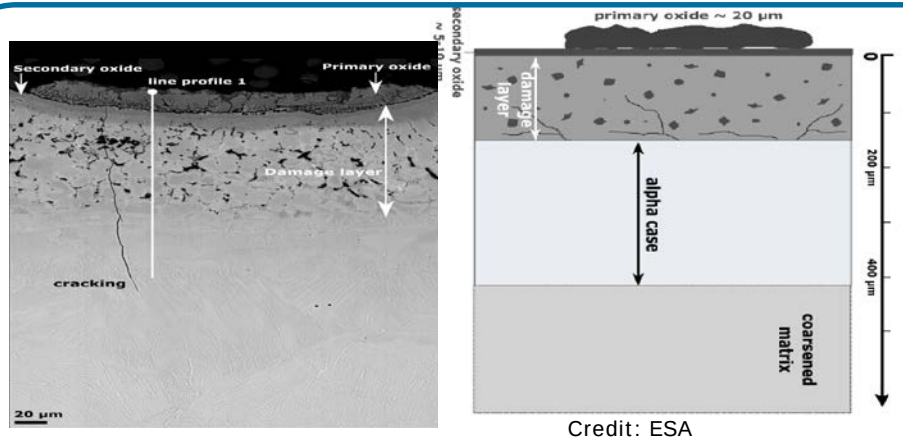


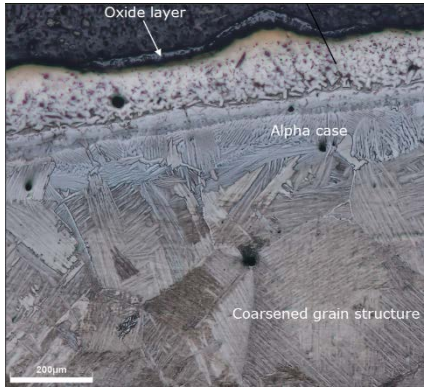


Post PWT investigation

- **Tested sample dimension (mm) and weight (g)**
- **Photographic evidences of the sample**
- **Surface analysis of the sample, morphology (LOM and SEM)**
- **Analysis of the oxide layer (crystalline phase): XRD, Raman spectroscopy**
- **Microstructure of metals and thickness of the oxides formed (LOM)**
- **Hardness profile from front surface to back surface**

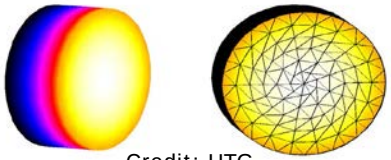




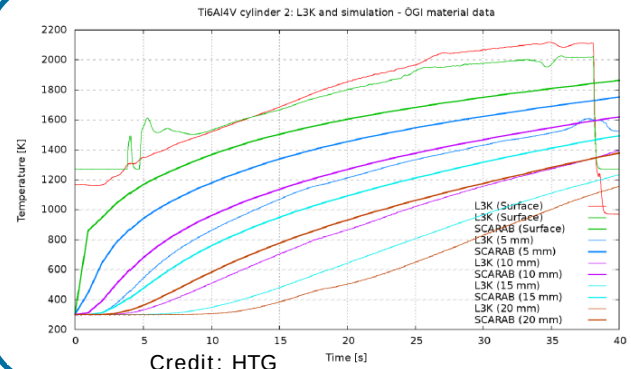


Plasma Wind Tunnel Test simulation

- **PWT model of SAM and SCARAB used**
- **Use of thermophysical properties measured**



Credit: HTG



Credit: HTG

Material	Status of Modelling Accuracy	TRP Impact on Modelling Accuracy	Open Points
Stainless Steel	GOOD	Improved with catalycity model	Heat-up rate lower than tests
Titanium	GOOD	Improved with catalycity model	Complex material at high temperatures
Silicon Carbide	GOOD	Improved with catalycity model	
Aluminium 7075	GOOD	Consolidated specific heats	
Aluminium 2099	GOOD	Established baseline aluminium model is applicable	
CFRP	FAIR	Established baseline model	Thermal conductivity Demise criteria Models for different types
GLARE	FAIR	Established baseline model	Basic data Demise criteria Layer-by-Layer Model

Global results

Metallic materials:

- Strong surface activity (oxide formation) impacting demise behavior (emissivity and catalicity)
- Ti6Al4V and 316L hardly demisable for LEO uncontrolled re entry conditions

Composite materials:

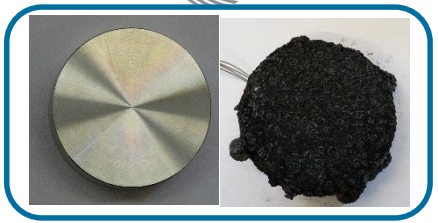
- Demise behavior strongly dependent of the fibers (type, UD, woven etc), matrix, and manufacturing process

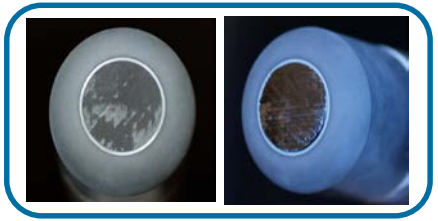
Ceramic materials:

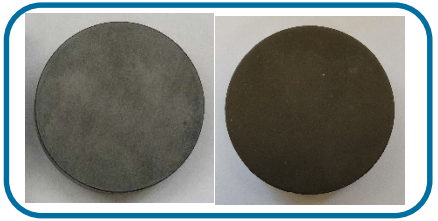
- SiC hardly demisable for LEO uncontrolled re entry conditions
- Uncertainties associated to possible fragmentation of complex ceramic components

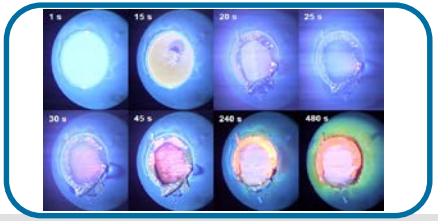
Structures & material combinations:

- Difficult to predict the demise mechanism at bigger scale



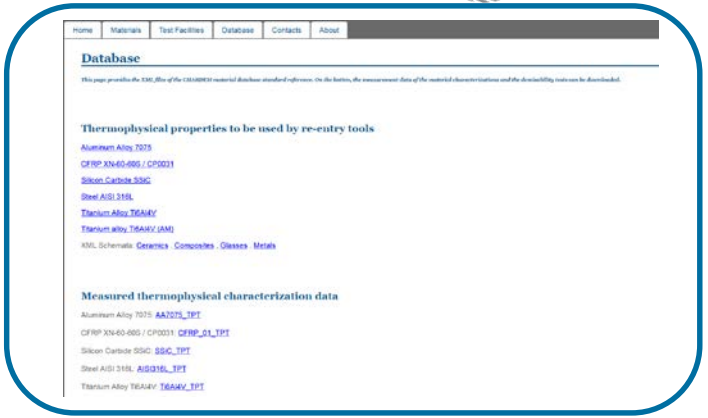


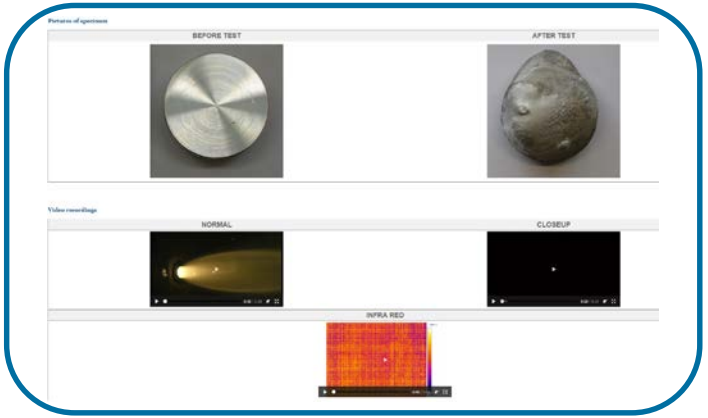




ESTIMATE database

- **European Space maTerIal deMisability dATabasE**
- **Accessible for European based companies**
- **Online by end of 2017**
- **Material thermophysical properties to be used by the codes**
- **Final reports of the two activities**
- **Plasma Wind Tunnel Test data (temperature profiles and videos) and test conditions for PWT test rebuild**

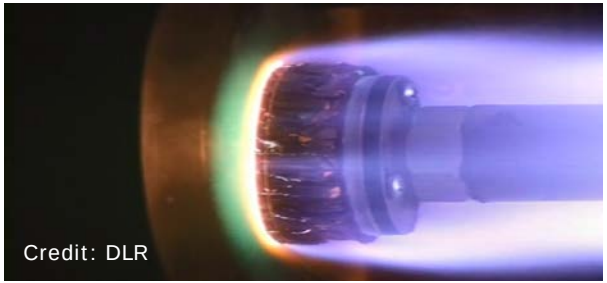




Next steps

- **Analysis of re-entered debris**

- **Additional tests required on composite materials and material combinations**



- **Additional test required for structural breaking understanding: Activity on demisable joints is ongoing (expected finish end of 2018)**

- **Observation campaign of controlled re-entry events**

Thank you for your attention

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