ESA TPS Activities for Sample Return Missions

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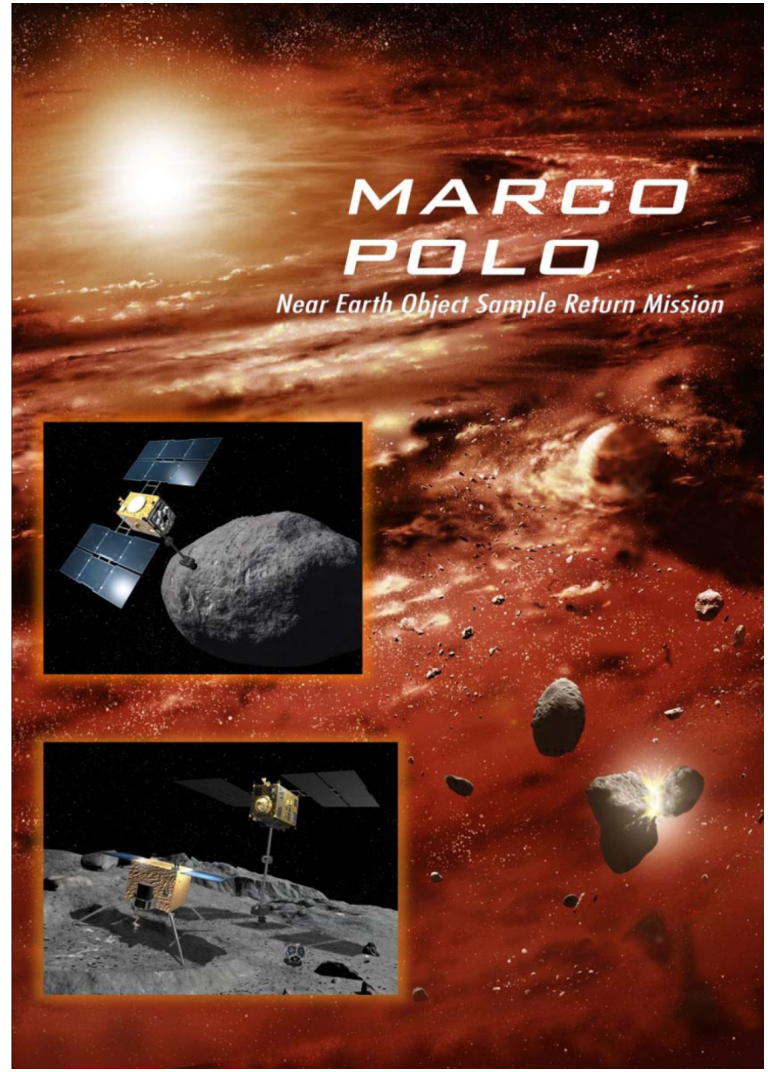
Outline

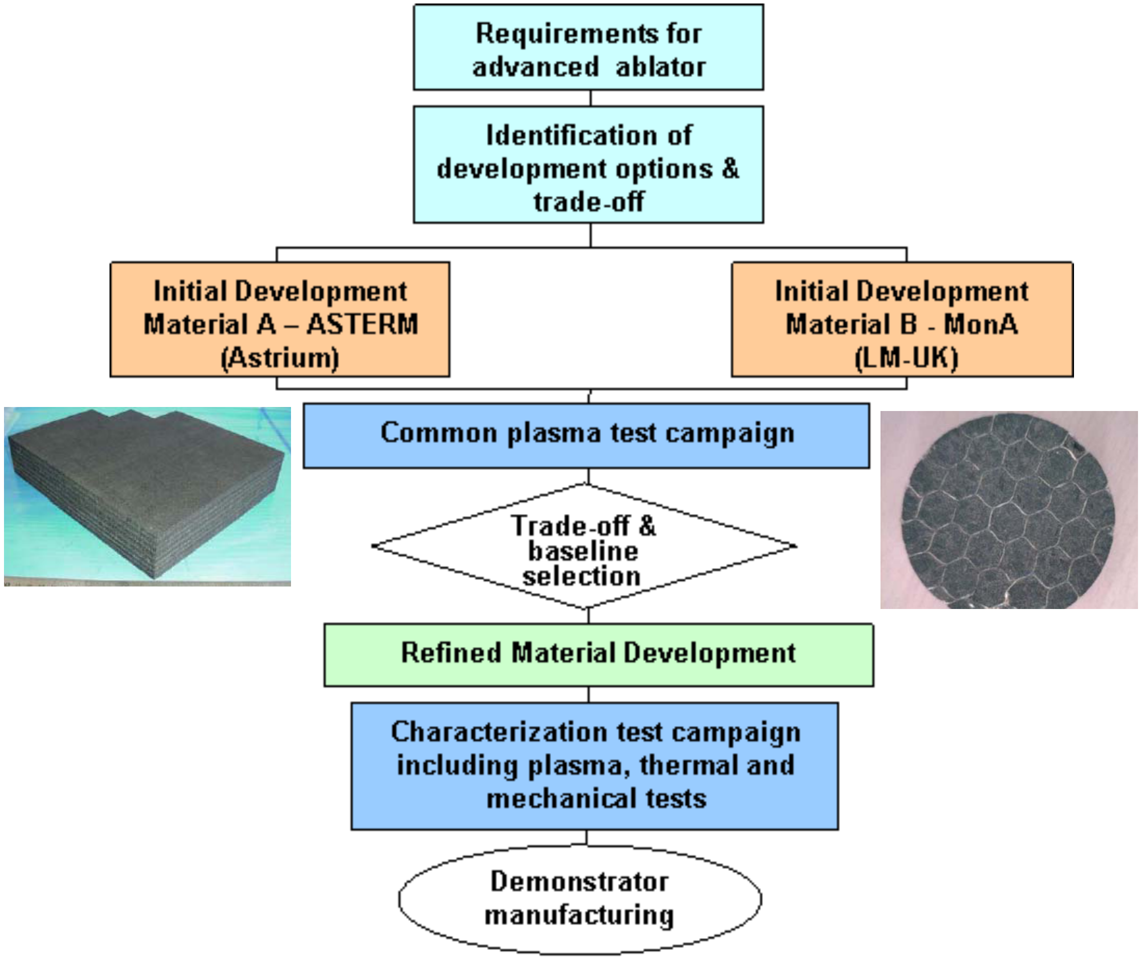
- **Development of European Ablation Material for sample return missions (DEAM)**
  - **Requirements**
  - **Development**
  - **Plasma and characterisation testing**
  - **Demonstrator**
  - **Planned material consolidation**
- **Preparation of a Numerical Test Case based on AQ61**
- **Upcoming/planned related TDA activities**

Load Assumptions and Requirements

- **Primary reference application: Earth re-entry capsule of sample return missions** (e.g. Mars, comets, asteroids)
- Potential secondary applications: Venus exploration, manned crew space transportation (CSTS), Advanced Return Vehicle (ARV)
- **Drivers:** Heat flux, pressure, mass
- Requirements derived from MSR and MarcoPolo mission studies:
  - **Peak heat flux up to 14 MW/m^2**
  - **Stagnation pressure up to 800 mbar**
  - **Area mass target of 15 kg/m^2** for a given entry heat flux profile (total heat load ~250 MJ/m^2) and structure temperature limit of 250°C
- **Base materials and manufacturing processes shall be available inside ESA member states**
- **Non-restricted use of fabricated products**



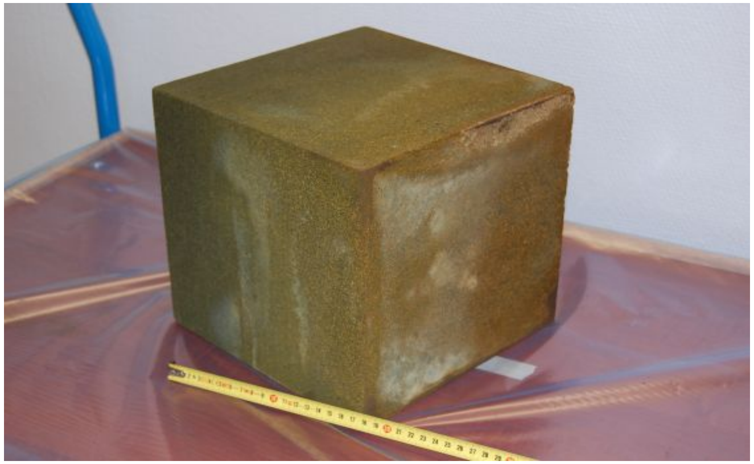
Development Approach



- Development of a European Ablative Material for sample return missions (DEAM)
- Two materials developed in parallel:
  - ASTERM by Astrium
  - MonA by Lockheed-Martin UK Ampthill
- Prime contractor: HPS-PT
- Plasma testing by DLR & IRS
- Characterisation by AAC
- Mathematical modelling by FGE
- Common plasma tests and trade-off indicated high potential for both materials, but also involving specific risks.
- Therefore refined development continued for both materials.

ASTERM Development by Astrium

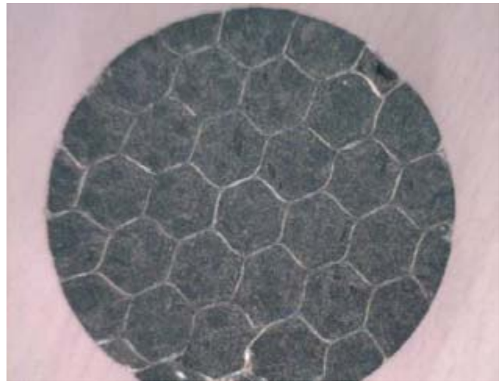
- Aurora-study in 2003/4 showed that no existing European material was able to within the ERC loads while coping with the stringent mass requirements.
- Astrium initiated development for an Ablator for Rapid Earth Re-entry (ARER).
- Development continued within the ESA-DEAM activity and in parallel under Astrium internal R&D.
- Material is now referred to under the trademark ASTERM.
- Based on heritage from AQ61, however, compressed carbon-felts are replaced by rigid carbon fiber blocks.
- ASTERM manufacturing process:
  - Rigid graphite felt
  - Impregnation with phenolic resin
  - Polymerisation
  - Final machining
  - Bonding to substrate
- Significant reduction of manufacturing effort compared to AQ61, enabling large scale production



- Manufacturing approach allows large range of final material densities (240 to 550 kg/m^3)
- Manufactured densities: 280 kg/m^3 (tested by Astrium), 350 kg/m^3 (tested in DEAM) and 420 kg/m^3
- ASTERM entirely uses standard European raw materials and available Astrium facilities

MonA Development by LMUK Ampthill

- MonA (Monolithic Ablator) was originally developed and partially qualified by Lockheed Martin US Denver for potential use on the NASA Orion Manned Capsule.
- Lockheed Martin UK Ampthill has been granted the opportunity to transition the material into Europe.
- MonA is a carbon-phenolic material that structurally reinforced by packing it into a phenolic honeycomb (Flex-Core ©).
- Overall density can be adapted in a range of 300 to 390 kg/m^3.
- Current development is under ITAR control.
  - TAA (Technical Assistance Agreement) was placed controlling the use and access of material samples and material data between the DEAM partners.
  - MLA (Manufacturing License Agreement) was placed enabling the exchange of fabrication information between LMUS and LMUK.

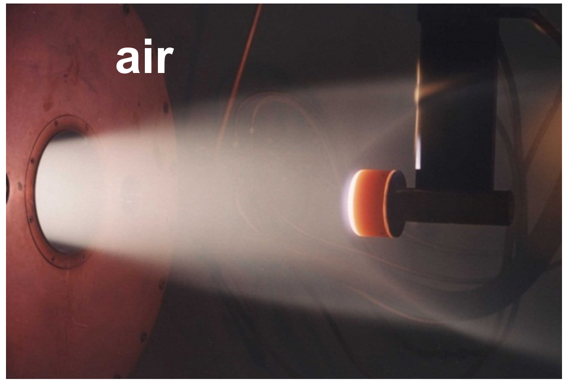


- European suppliers were identified and selected for adequate constituent raw materials.
- Manufacturing processes and methodologies have been established at LMUK Ampthill.
- Initial arc jet tests in 2010 used coupons cut from panels manufactured by LMUS Denver.
- Arc jet test campaigns and material characterisation in 2012 done on MonA material manufactured by LMUK Ampthill based on European raw materials.

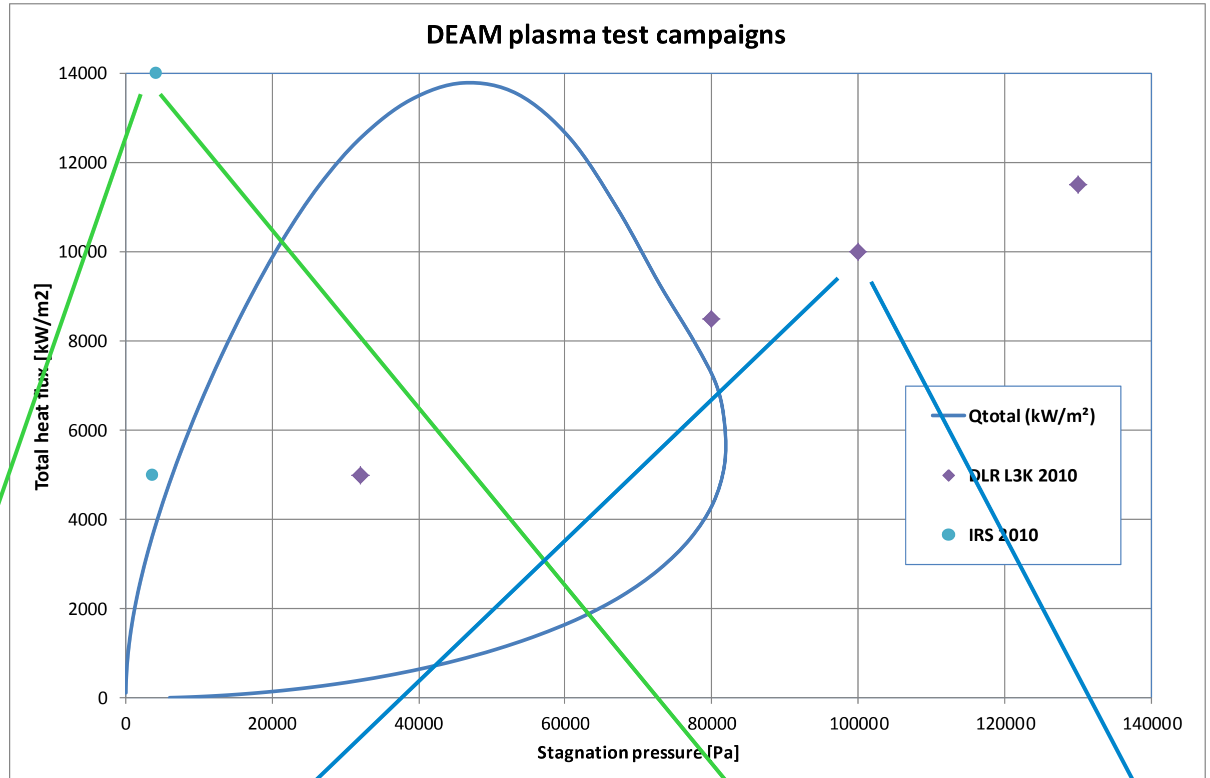
Plasma Testing (1/4)

- Initial plasma test campaign in 2010 on both materials after initial development phase
  - ASTERM with 350 kg/m^3
  - MonA with 350 kg/m^3 from plates manufactured by LMUS Denver

- Campaign comprised tests in two two plasma facilities
  - L3K at DLR Cologne
    - Tests at specified stagnation pressure level of 800 mbar, but heat fluxes limited to 10 MW/m^2
    - Additional tests at 11.5 MW/m^2 but too high stagnation pressure of 1300 mbar
  - PWK-RD5 at IRS Stuttgart
    - Magnetoplasmadynamic (MPD) wind tunnel
    - Allows operation at specified heat flux level of 14 MW/m^2, but related pressure levels only around 40 mbar



Plasma Testing (2/4)



ASTERM

MonA

Plasma Testing (3/4)

- Second plasma test campaign in 2012 on both materials after refined development phase
  - ASTERM with 350 kg/m^3 (improved homogeneity, consolidated process)
  - MonA with 350 kg/m^3 (produced by LMUK Ampthill with European raw materials)

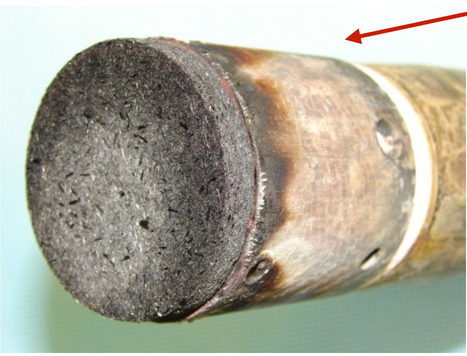
- Again two plasma facilities
  - L3K at DLR Cologne
    - Segmented arc heater increased from 4- to 5-packs to achieve an increased specific enthalpy of 15.9 MJ/kg

	DLR-A	DLR-B	DLR-C	DLR-D
Distance from nozzle exit [mm]	160	140	100	75
Pitot pressure [hPa]	210	290	588	840
Cold wall heat flux rate [MW/m^2]	6.1	7.2	10.1	12.8

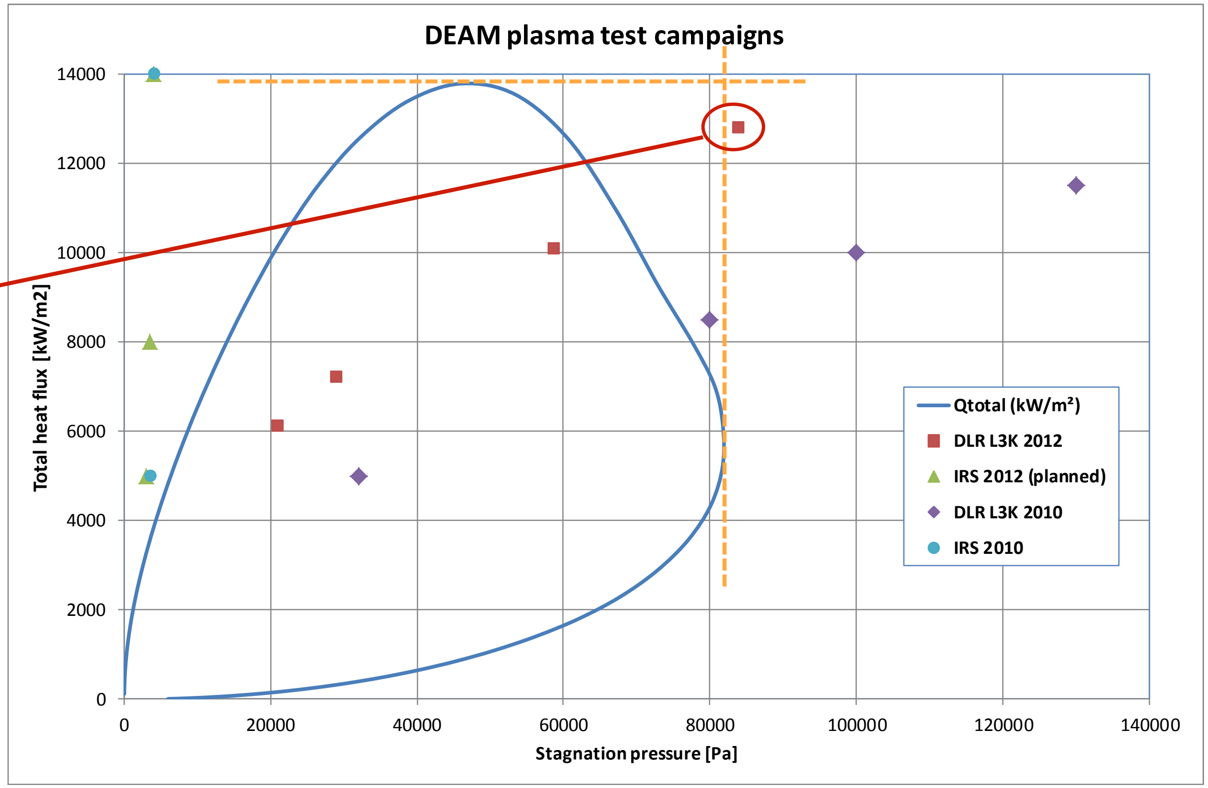
  - PWK-RD5 at IRS Stuttgart
    - Campaign currently ongoing

	IRS-A	IRS-B	IRS-C
Pitot pressure [hPa]	30	35	40
Cold wall heat flux rate [MW/m^2]	5	8	14

Plasma Testing (4/4)



ASTERM

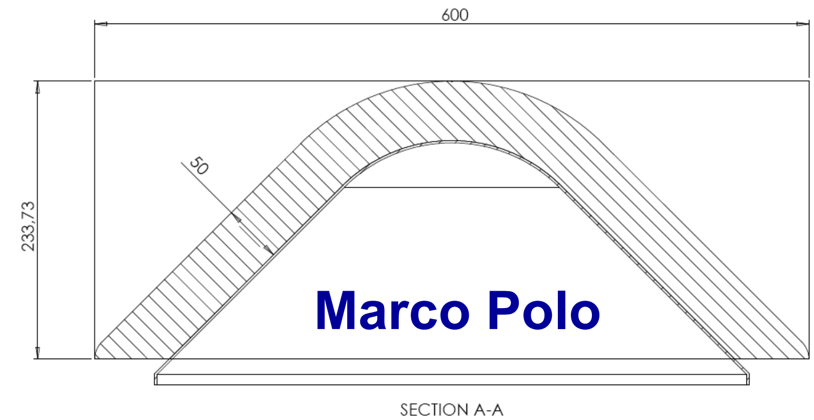


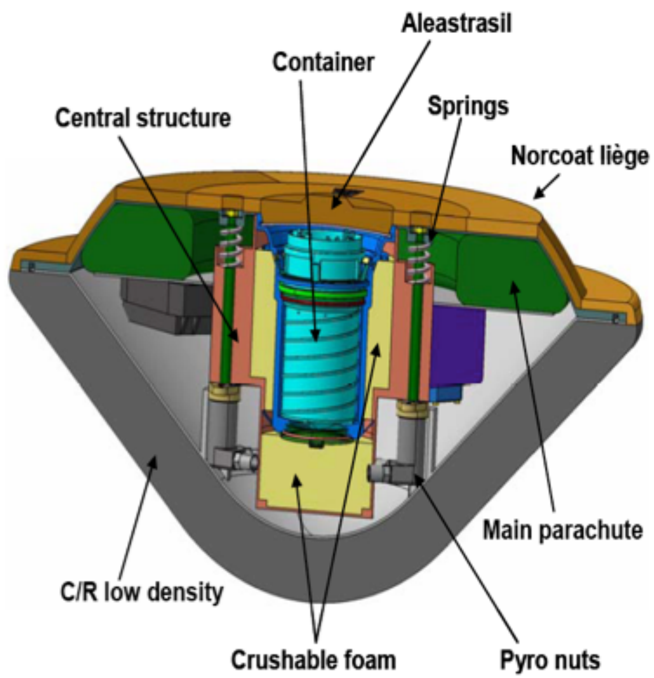
Material Characterisation

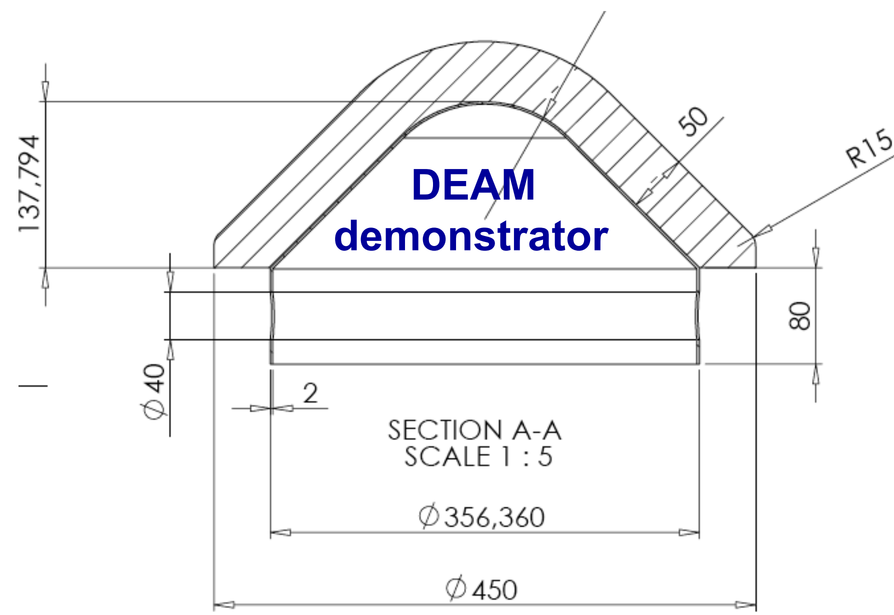
- Further material characterisation included
  - Density
  - TGA and DSC
  - specific heat (f(T), virgin and char) through DSC
  - thermal conductivity (f(T), virgin and char)
  - ablation characteristics (from DSC) through DSC
  - mechanical strength properties (f(T), virgin and char)

TPS Demonstrator based on ASTERM (1/2)

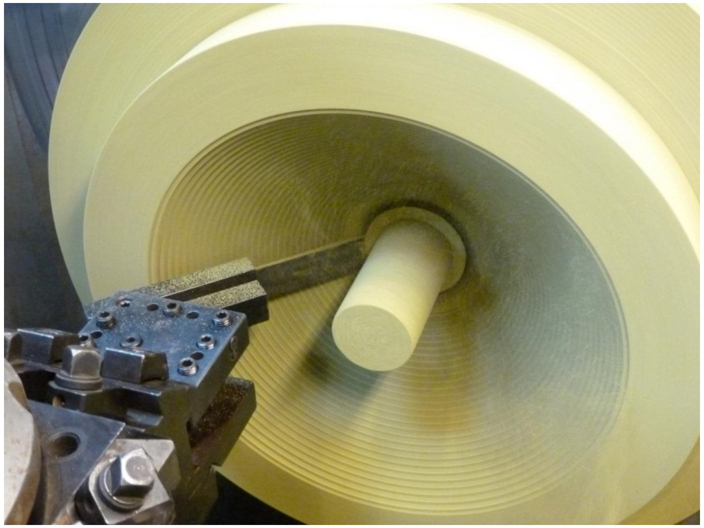
- Demonstrator
  - including ablative TPS produced with ASTERM
  - and a dummy substructure in Aluminium
- Marco Polo design was chosen, downscaled to 80% in order to match current raw material availability.

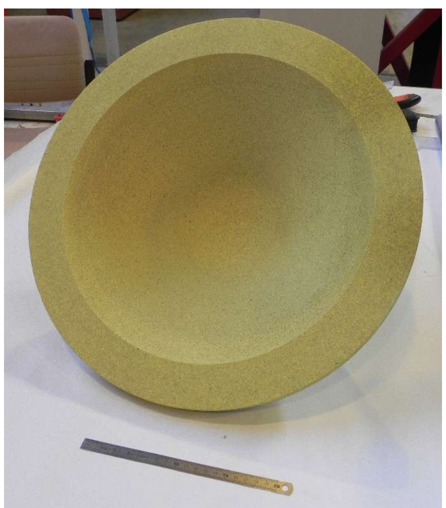






TPS Demonstrator
based on ASTERM (2/2)





Delta-development and Pre-qualification of a European lightweight Ablative material for sample return missions (DEAM-2)

- Objectives / planned work
  - Consolidation of material definition and related manufacturing process
  - Complete material characterisation
  - “Extensive” plasma testing
  - Pre-qualification including plasma tests on assemblies with interfaces
  - TPS large-scale demonstrator manufacturing

- Goal: TRL-6 by 2014
- Status: Kick-off planned within the summer

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Preparation of a Numerical Test Case based on AQ61 (1/2)

- Dedicated plasma test campaign was performed at DLR
- Flat-faced cylindrical samples (50mm diatmer)
- Three thermocouples each at 5, 10, and 20 mm depths

Operating conditions and facility parameters

Gas mass flow rate [g/s]	101
Reservoir pressure [hPa]	3750
Reservoir temperature [K]	6462
Specific enthalpy [MJ/kg]	15.9
Nozzle throat diameter [mm]	29
Nozzle exit diameter [mm]	50

Test conditions

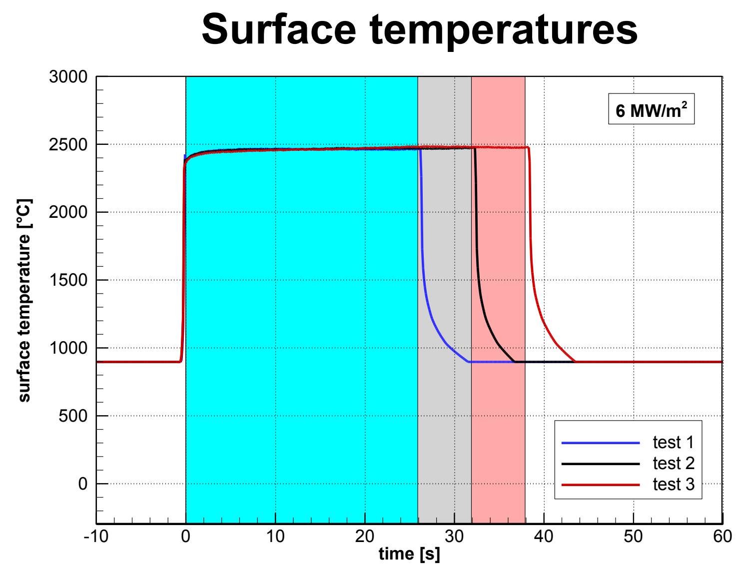
	FC-1	FC-2	FC-3
Distance from nozzle exit [mm]	160	100	75
Pitot pressure [hPa]	210	588	840
Cold wall heat flux rate [MW/m^2]	6.1	10.1	12.8

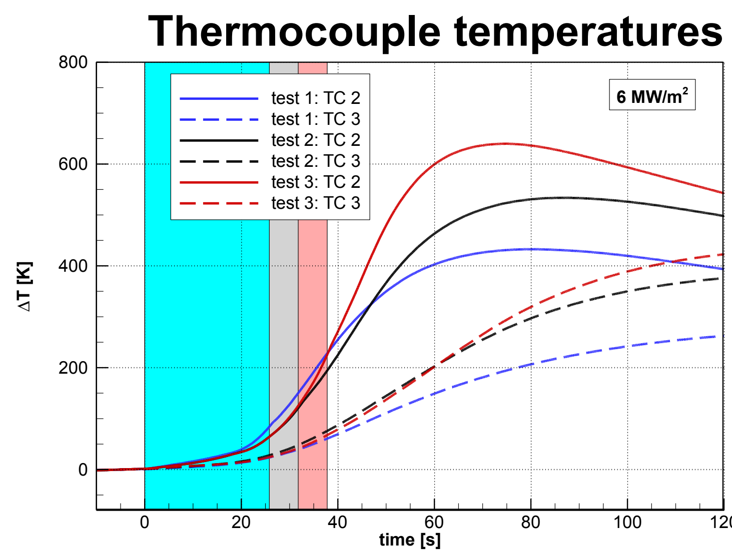
Test No.	Test condition	Test duration	H. Load [MJ/m^2]
1	FC-1	26 s	130
2	FC-1	32 s	160
3	FC-1	38 s	190
4	FC-2	13 s	130
5	FC-2	16 s	160
6	FC-2	19 s	190
7	FC-3	10 s	130
8	FC-3	12 s	160
9	FC-3	14 s	190

Preparation of a Numerical Test Case based on AQ61 (2/2)

- Available test data
  - Surface temperature by pyrometers
  - Thermocouple temperature (3 depths)
  - Mass loss
  - Surface recession

- Basic material characterisation data available
- More detailed characterisation and additional ablation parameters might have to be derived





Characterization of TPS materials of High-density for High Heat flux re-entry applications (CT3H)

- Objectives
  - Characterize and test in laboratory environment samples of an existing European ablative heatshield material which has flight track records and which is suited to withstand the Earth re-entry conditions of a mission such as MSR.
- Background: Planetary protection

Ablative Material Optimisation and Definition of Material Families adaptable to various Applications (AMOF)

- Objective
  - Determine the limits of (an) ablative material(s) as function of key material parameters (e.g. density), and derive semi-empirical models for the optimisation towards the requirements coming from a new application.

Planned TDA Activities (4/6)

Design of a crushable TPS for the ERC

- Objectives
  - Investigate ways of building a multifunctional crushable TPS structure that not only acts as a heat shield for planetary re-entry but also brings structural integrity and mechanical shock damping capability for hard landing.

Material development for crushable TPS for the ERC

- Objective
  - Develop a material that:
    - Will be attached to an ablative material and to a cold structure
    - Will absorb the impact energy and limit the acceleration loads on the payload to acceptable values.
    - Will act as thermal insulation between the hot ablative material and the cold structure

Characterisation of high enthalpy facilities

- Objectives
  - Quantification and reduction of uncertainties on the knowledge of the main flow parameters of interest for the material testing (heat flux, pressure, enthalpy, …)
  - Standardisation of plasma test procedures

Announcement

7th TPS & HS workshop

9-12 April 2013
at CIRA facilities in Capua, Italy