Ongoing European Developments on Entry Heatshields and TPS Materials

Part 1: Heatshield Development for ExoMars EDL Demonstrator Module (EDM)

Part 2: Development of a European lightweight Ablative Material (DEAM) for extreme heat flux applications

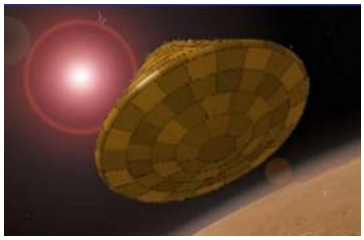
H. Ritter [1], O. Bayle [2], Y. Mignot [3], P. Portela [4], J-M. Bouilly [5], R. Sharda [6]

[1] ESA/ESTEC, The Netherlands
[2] ESA/ESTEC, The Netherlands
[3] EADS-Astrium, France
[4] HPS-Ltda, Portugal
[5] EADS-Astrium, France
[6] Lockheed Martin UK Ampthill, UK

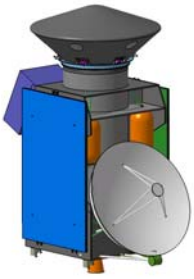
ExoMars EDM Heatshield Contents

Part 1: Heatshield Development for ExoMars EDL Demonstrator Module (EDM)

- ExoMars Missions Overview
- Heatshield Components
- TPS Material Selection, Manufacturing & Integration
- Frontshield Design
- Backshield Design
- TPS Sizing
- Verification Testing
- Instrumentation

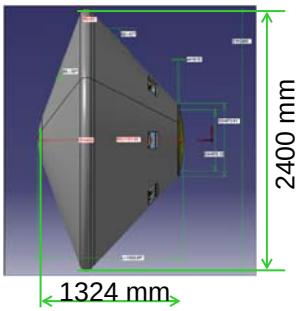


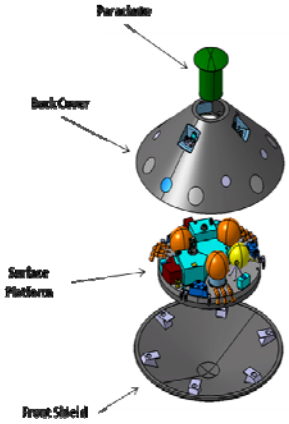
ExoMars Missions Overview



2016 Mission

- ESA-supplied Trace Gas Orbiter
- ESA-supplied EDL Demonstrator Module (EDM)





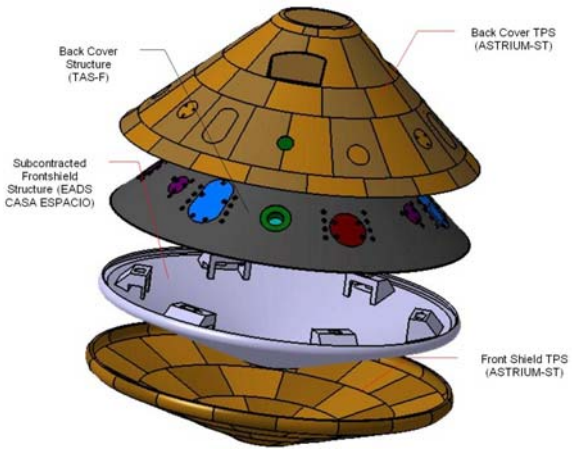
2018 Mission

- NASA-supplied Carrier and EDL (MSL derivative)
- Joint ESA-NASA Rover

- Heat Shield
- Parachute
- Doppler Radar
- Liquid Propulsion
- Impact attenuation

Heatshield Components

- Frontshield TPS
  - Norcoat Liege
  - Astrium-ST, France
- Frontshield structure
  - Al-honeycomb with CFRP skins
  - CASA, Spain
- Backcover TPS
  - Norcoat Liege
  - Astrium-ST, France
- Backcover structure
  - Al-honeycomb with CFRP skins
  - TAS-F, France
- Bioseal at FS/BCV interface
  - V-ring design in Aluminum
  - TAS-F, France
- Frontshield diameter: 2.4m



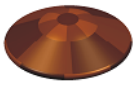
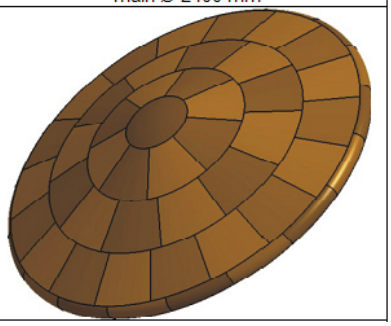
TPS Material Selection, Manufacturing & Integration

- Frontshield and backcover TPS made in Norcoat Liege ablative tiles
- Heritage from ARD backcover, Beagle-2 and Netlander qualification
- Trade-off resulted in simpler design, easier implementation and slightly lower mass than alternative solutions like AQ60 or Picsil
- Dedicated outgassing and sterilization process to meet requirements for Mars entry ➔ Outgassed Norcoat Liege HPK FI

- Tiles individually machined on all six faces
- Tiles individually bonded with silicone glue ESP 495
- Same glue used to fill gaps between tiles

Beagle-2 tile bonding process

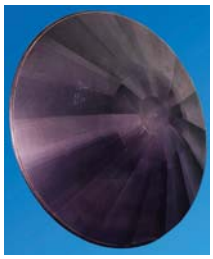
Comparison Beagle-2 - ExoMars

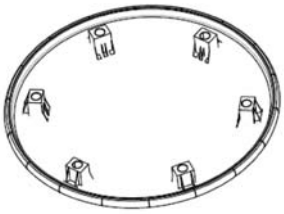
Beagle 2 main Ø 900 mm	ExoMars main Ø 2400 mm
	

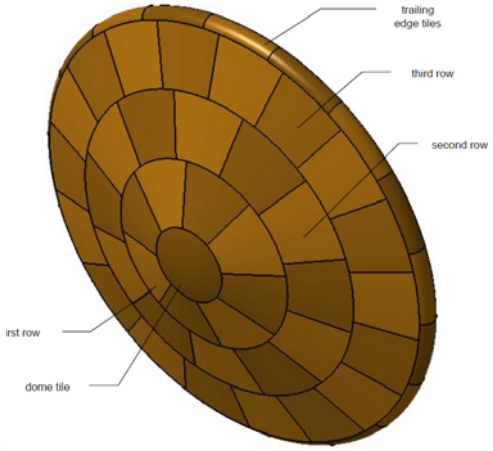
Frontshield Design

- Total of 57 tiles
- 5 different types of tiles
- Bonded in staggered rows to avoid longitudinal flow
- Trade-off on straight or inclined I/Fs ongoing

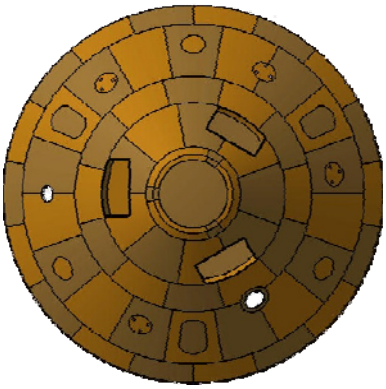
- 20mm sandwich structure with Al-honeycomb and CFRP skins
- Temperature limit: 180°C
- Based on Huygens heritage

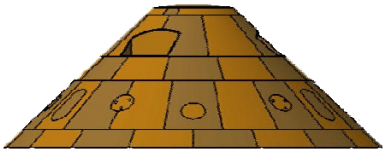




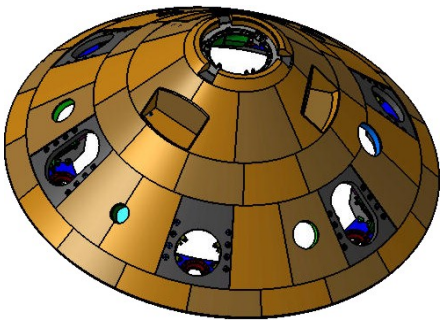


Backshield Design (1/2)

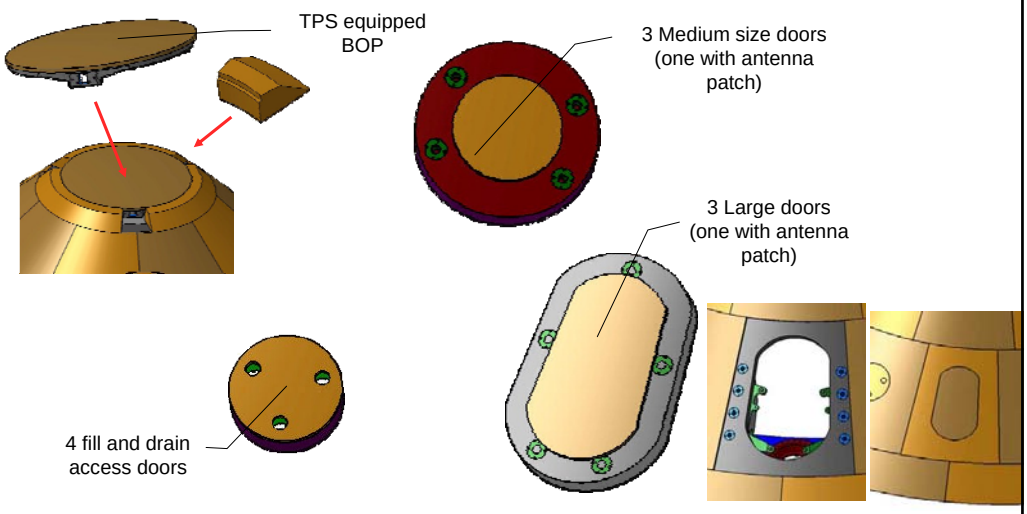




- 89 tiles in Norcoat Liege
- 2 tiles in Norcoat 4011 over antennas
- 16 main types
- 29 sub-types linked to specific cut-outs
- Bonded on backcover sandwich structure
- Design not yet frozen

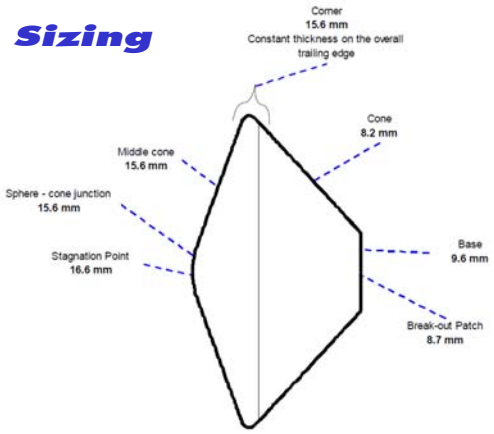


Backshield Design (2/2)

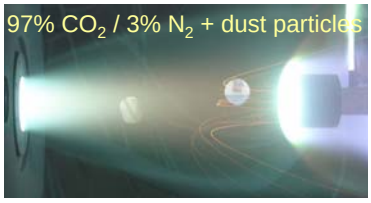


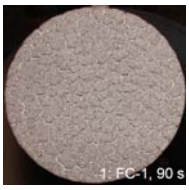
TPS Sizing

- TPS sizing performed by Astrium using the Amaryllis ablation code
- Total thickness is derived from:
- Computed thickness
  - Material and model uncertainties (~15-18%)
  - Manufacturing thickness tolerance (0.2mm)
  - Margin for dust erosion (3.5mm TBC, frontshield only)



- Margin for dust erosion derived from dedicated plasma test campaign in L3K at DLR with addition of dust particles of various materials, diameters and masses.





Verification Testing (1/3)

Assembly Qualification – air versus CO_2

- Performed in Astrium's SIMOUN arc jet facility
- High heat flux tests performed in air since CO_2 tests require considerable electrical power limiting the achievable heat flux in CO_2 to about 1 MW/m^2
- Specific campaign on identical samples and identical test conditions to assess material behavior under air and CO_2
- Results demonstrate that under air and CO_2, outgassed Norcoat Liege shows a very similar behavior in terms of
  - Material final aspect (including micrographic analyses)
  - Measured temperatures and thermal performance
  - Final surface recession

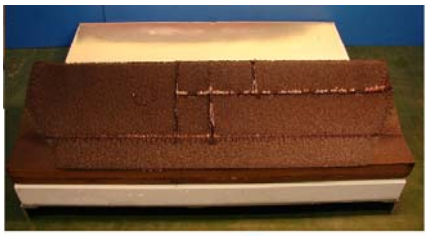
Verification Testing (2/3)

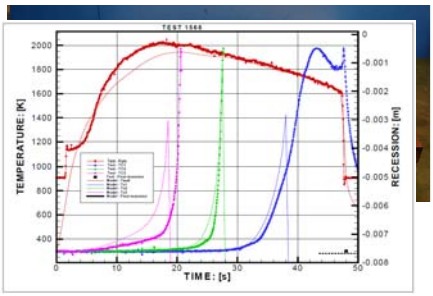
Assembly verification – including joint I/F's

- Straight inter-panel joint versus 20° inclination
- Silicone glue ESP495 to fill inter-tile joints
- ~1.8 MW/m^2 cold wall heat flux, ~58MJ/m^2 heat load , ~200 mbar wall pressure

- Homogeneous recession
- Total ablation identical on both samples
- No significant loss of inter-tile adhesive
- Crusts formation along gaps in parallel to flow

- Results showed conservatism with respect to predicted backface temperature and recession
- Thermal, pyrolysis and ablative response model correlated with test data
  - Improved ablation model developed
- Tests did not show significant advantage or disadvantage for either of the two concepts

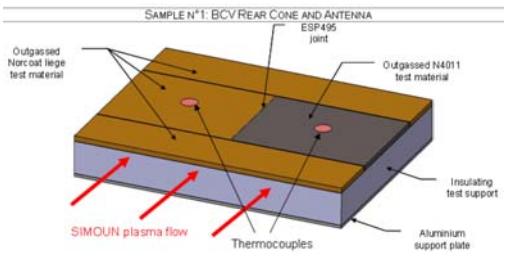




Verification Testing (3/3)

Assembly verification – Back cover

- Objectives:
  - Improve knowledge on material behaviour at low heat flux (without ablation)
  - Verify and consolidate the design of the BCV tiles pattern
  - Verify interface to Norcoat 4011 (used over antennas)
- Tests performed in CO_2 applying ATDB 5.1
- Completed mid May 2011
- Evaluation ongoing



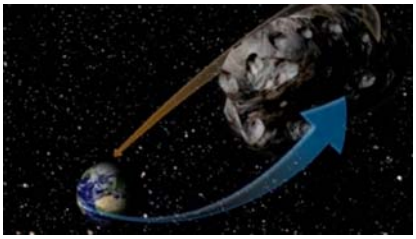
Instrumentation

- Front Shield
  - 7 thermal plugs including at least 3 thermocouples
  - 7 thermistors
  - 5 pressure sensors
- Back Shell
  - 7 thermal plugs including at least 2 thermocouples
  - 3 thermistors
  - 5 pressure sensors
- Potential additions on back shell (still TBC)
  - Combined aerothermal and calorimeter sensor units
    - To measure pressure, temperature and total heat flux
  - Radiometer sensors to measure radiative flux (based on thermopiles)
  - Recession sensors

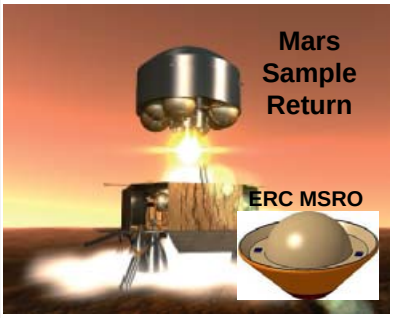
Ablative Material Development Contents

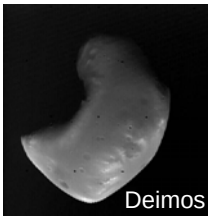
Part 2: Development of a European lightweight Ablative Material (DEAM) for extreme heat flux applications

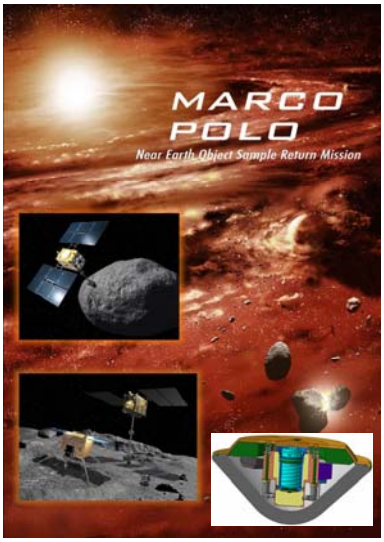
- Sample Return Mission Studies
- Motivation and History
- Load Assumptions and Requirements
- Development Approach
- ASTERM Development by Astrium
- MonA Development by LMUK Ampthill
- Mathematical Modelling
- Material Testing
- Further Steps



Sample Return Mission Studies







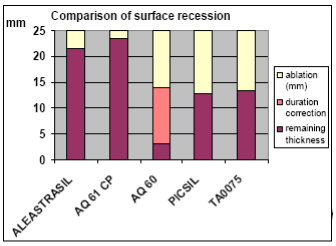
Motivation

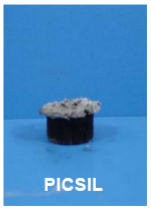
- Earth return from extraterrestrial bodies involves hyperbolic trajectory resulting in atmospheric entry velocities of typically around or above 12 km/s
- Resulting peak heat fluxes in the order of 10-20 MW/m^2
- Dynamic pressure loads around 800-1000 mbar
- Stringent mass budget since Earth return capsule is subject to “double” delta-V (to the object and back to Earth)

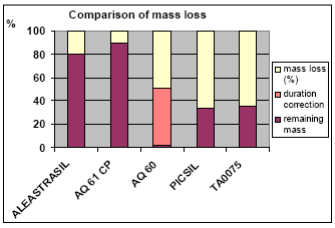
- Capability to design and manufacture the heatshield for future sample return missions is considered of high importance for Europe within potential international cooperation’s.
- ESA therefore initiated a dedicated activity aiming at the Development of a European lightweight Ablative Material (DEAM) for extreme heat flux applications.

History

- Aurora study in 2003/2004 to screen existing European ablators with respect to their capabilities for sample return missions

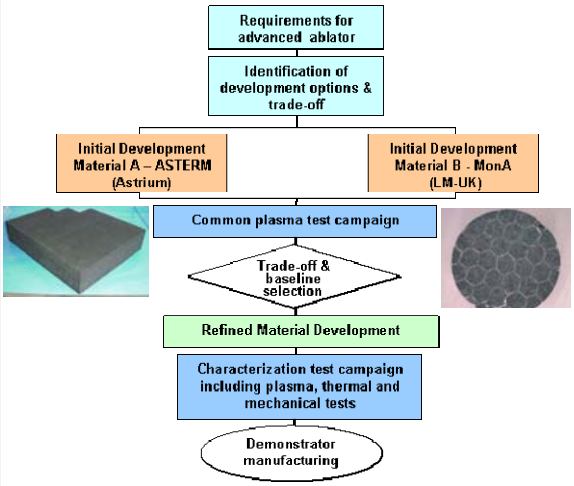






- Tests performed in COMETE (inductively heated) at 6.9 MW/m^2 with total heat load of 172 MJ/m^2.
- Good performance of high density materials
- However, none of the materials was found to cope simultaneously with the high heat fluxes and stringent mass requirement.

Development Approach within DEAM



- Various interesting developments identified, but maturity (in 2008) was mostly too low to reach TRL 5 by 2011.
- Trade-off resulted in two materials which were selected for continued technological development under the DEAM activity:
  1. ARER from EADS-Astrium
  2. MonA from Lockheed-Martin
- Prime contractor: HPS
- Common plasma tests and trade-off indicated high potential for both materials, but also involving specific risks.
- Decided to continue refined development and characterization for both materials.
- Charaterization and 2nd plasma test campaign planned for this summer

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, ARV (Advanced Return Vehicle)
- Main technical driver is the capability to withstand the expected entry environment while keeping the heatshield mass at a minimum.
- Requirements derived from MSR and MarcoPolo mission studies:
  - **Peak heat flux up to 14 MW/m^2**
  - **Dynamic pressure up to 800 mbar in air**
  - Both values could eventually be higher, depending on mission design and resulting entry velocity. Above requirements represent a compromise such to allow relevant material testing in existing facilities.
  - Area mass target of 15 kg/m^2 for a given entry heat flux profile (total heat load ~250 MJ/m^2) while providing adequate thermal protection for underlying structure (structure temperature limit: 250°C).
  - Set of requirements completed considering ablation performance, mechanical, material, interface, environmental, physical, PA and design requirements.
- **Base materials and manufacturing processes shall be available inside ESA member states**
- **Non-restricted use of fabricated products**
- Potential to reach TRL 5 by 2011 considered during initial trade-off

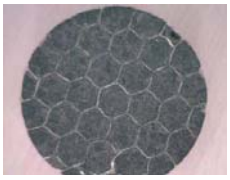
ASTERM Development by Astrium

- Following Aurora-study in 2003/4, Astrium initiated internal R&D for an Ablator for Rapid Earth Re-entry (ARER)
- After successful first plasma tests, ARER development is continued under the support of internal R&D and in parallel within the ESA-DEAM activity
- Material is now referred to under the trademark ASTERM
- Based on heritage from AQ61 (low density carbon-phenolic material manufactured by impregnating pieces of carbon felts compressed to the right density during the impregnation process)
- 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, 350 kg/m^3 (tested) 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 previously 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.
- TAA (Technical Assistance Agreement) has been placed allowing LMUS Denver and LMUK Ampthill.
- MonA is a carbon-phenolic material that is 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.

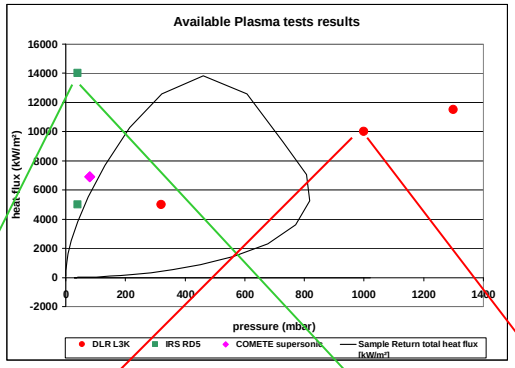


- Arc jet tests were performed on coupons cut from panels manufactured by LMUS Denver.
- European suppliers were identified and selected for adequate constituent raw materials.
- Manufacturing processes and methodologies have been established at LMUK Ampthill and first sample material been produced.
- Physical similarity to the US MonA was demonstrated by laboratory tests.
- Processing methods at LMUK Ampthill are now refined to produce a homogeneous material.
- Coupon and plate samples will be produced for upcoming test campaign.

Material Testing

- Common plasma test campaign performed on both materials after initial development phase.
- Two plasma facilities
  - 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
  - L3K at DLR Cologne
    - Allows operation at specified pressure level of 800 mbar, but only reaching heat flux levels of around 8-10 MW/m^2
    - Slightly higher heat flux levels were reached, but at too high pressure levels

Material Testing (1/2)



ASTERM

MonA

Material Testing (2/2)

- Additional plasma test campaign planned after completion of ongoing refined development phase
- Modification of the L3K facility at DLR is currently performed aiming to improve the representativeness of the test conditions
- Expected envelope:
  - 14 MW/m^2 at 1000mbar
  - 11 MW/m^2 at 800mbar

- In parallel, initial material characterisation will be performed including
  - thermal conductivity (f(T), virgin and char)
  - specific heat (f(T), virgin and char)
  - mechanical strength properties (f(T), virgin and char)
  - ablation characteristics (from DSC)

Mathematical Modelling

- Mathematical modelling of both materials initiated
- by FGE (Fluid Gravity Engineering, UK)
- FABL (Fluid Gravity's ABLation code)
  - Based on implicit final difference models
  - Using a multi-component Arrhenius decomposition model
  - Allowing to model in-depth response and the surface recession
- Intention is
  - to perform pre- and post-test analysis of planned arc jet tests campaign;
  - to support further improvement of the materials by numerical results;
  - in case of ASTERM, to compare the material performance to PICA.

Further Steps

Ongoing activity

- Refined development almost completed
- Further plasma test campaign and initial characterisation planned this summer
- Production of heat shield demonstrator with ASTERM (diameter about 450mm, scaled from MarcoPolo heatshield)

Follow-on activities (ITT's planned by end 2011)

- Delta-development and pre-qualification
  - Completion of development, including fine-tuning of the material composition to match the refined technical requirements derived from ongoing mission studies
  - Extensive characterisation and pre-qualification
  - Manufacturing of tile assemblies with interfaces
  - Transition to relevant large scale manufacturing
- Tailoring towards material family
  - Determine material limits as function of key parameters (e.g. density)
  - Derive semi-empirical models for optimisation towards requirements coming from new mission applications

Thank you !