AEROFAST

GA n° 218797

IPPW8, Portsmouth, 06-10/06/2011

AEROFAST :
Development of a cork based material for Martian Aerocapture and 3D sizing of the vehicle heat shield

IPPW8 - Session TPS-7A

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SAMTECH

AMORIM Amorim Cork Composites

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Funded under Seventh Framework Programme

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Overview

- AEROFAST project objective & organization
- Existing cork TPS & status
- Ablative Thermal Protections development
  - Development strategy
  - Innovation ways
  - Preliminary characterization tests and selection
  - Plasma test
- Spacecraft trade-off & flight environment
- 1D thermal and ablative analysis
- 3D thermal and ablative analysis
- Conclusion

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AEROFAST project objective & organization

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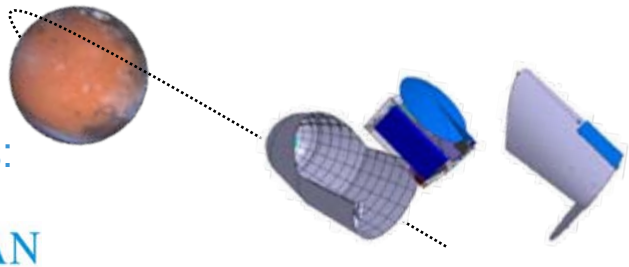
- European Union R&D project aiming at increasing the TRL of ***Aerocapture*** technology for efficient Mars Exploration missions



⇨ 12 European partners, ASTRIUM SAS prime, 6 workpackages:

⇨ AEROFAST top 5 objectives:

- Obj1: Define a project of aerocapture demonstration
- Obj2: Increasing TRL planetary relative navigation and aerocapture algorithm up to 5.
- Obj3: Build a breadboard to test in real time the pre-aerocapture and aerocapture GNC algorithms.
- **Obj4: Demonstrate/prototype the thermal protection system.**
- Obj5: Define on-board instrumentation for aerocapture phase recovery.

Existing cork TPS & status

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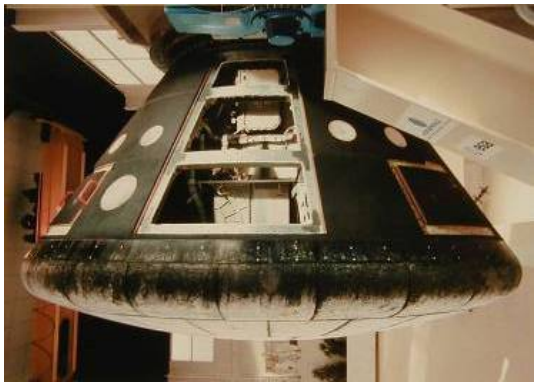
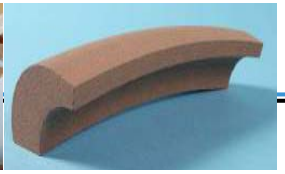
ASTRIUM AN EADS COMPANY ⇨Norcoat Liège©

Used on:

- Launchers (Ariane 5, M51)
- ARD cone & back-cover
- Beagle 2 (assembly process)
- ExoMars (CO_2 qualified)





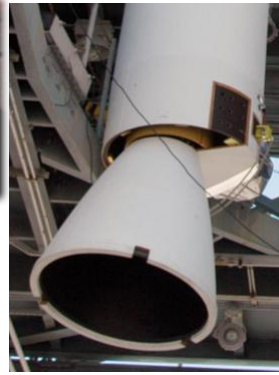
P45-P50 ⇦ AMORIM Amorim Cork Composites

Used on:

- SRB of Space Shuttle

(booster nose cone, forward and aft skirt...)

- Delta rockets (booster nose cone, frustum ...)



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Development strategy

TPS Needs and Status

- Collect data & inputs
- List & compare potential TP
- Requirements & Trade-off criteria
- Improvement Innovation ways

2 families:
- **Reinforced material**
- **Superlight material**

Cork based ablative solutions

- Material screening
- Test new combinations with cork
- Basic characterization
- Selection of 2/3 formulations

Non-ablative Solutions

- Investigation TPS concepts
- Thermal sizing
- Preliminary TPS design
- Engineering budget

Iterative improvement process

Synthesis

- Collect data
- Improvement ways
- Prototyping
- Update TPS information
- Final TPS trade-off

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Innovation ways

New formulations were proposed (up to 25) based on a "development road map":

State of the art reference material
- Norcoat Liège
- P50

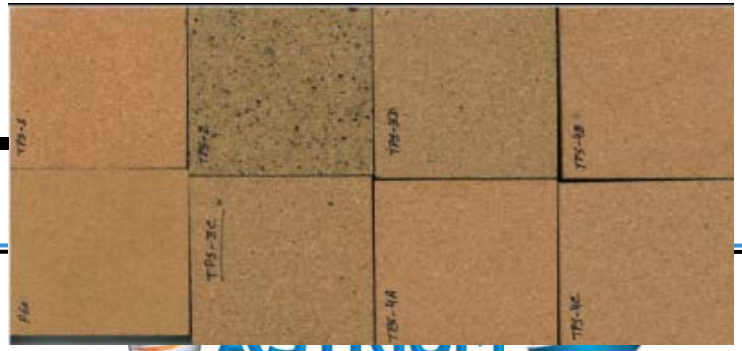
Reinforcements
- Carbon fibers
- basalt fibers

Fillers
- Hollow glass spheres
- Hollow silica spheres
- Ceramics
- Carbon fibers
- Basalt fibers

Resin
- Phenolic
- Furanic
- PU-TDI base
- High charred polymer

Mixing operations
- Parameters
- Blade type
- Vertical
- horizontal

Mixing additives
- Plasticizers
- Surfactants
- Lubricants



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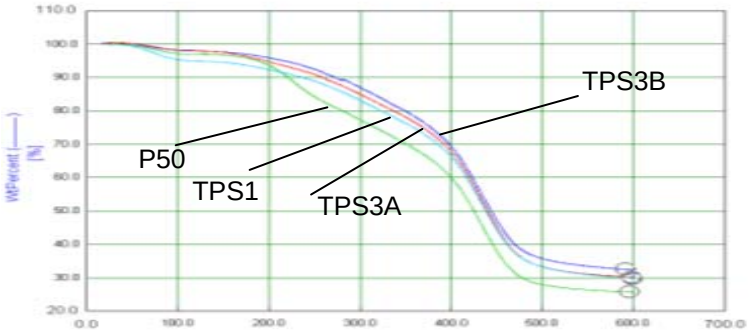
Preliminary characterization tests & selection

- Basic characterization perform for all formulations & ref material
  - Density
  - Hardness
  - Tensile
  - Elongation
  - Compression
  - Flexibility
  - Mass loss @ 1000ºC (TGA)



- For the most interesting samples fire tests were performed
  - Test conditions : 75 kW/m2 during 300 s
  - Calorimetric measurements
  - Mass loss

- Selection of the 4+3 best candidates based on:
  - Material recession (mass loss under fire test)
  - Material mechanical integrity (disaggregation, ash)
  - Surface roughness
  - Cracks (number, depth, width)

- Deeper thermal investigation followed on the most promising formulations (TGA, *k*, Cp...)

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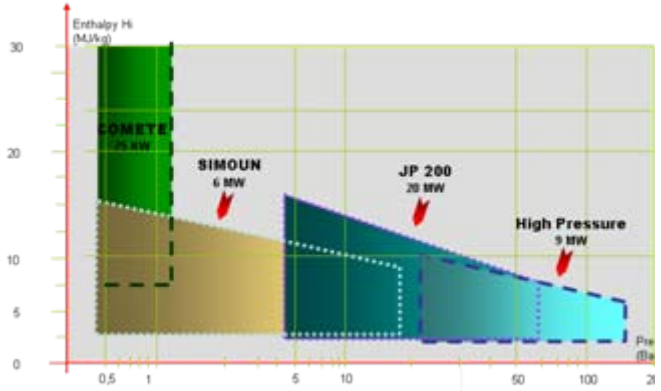
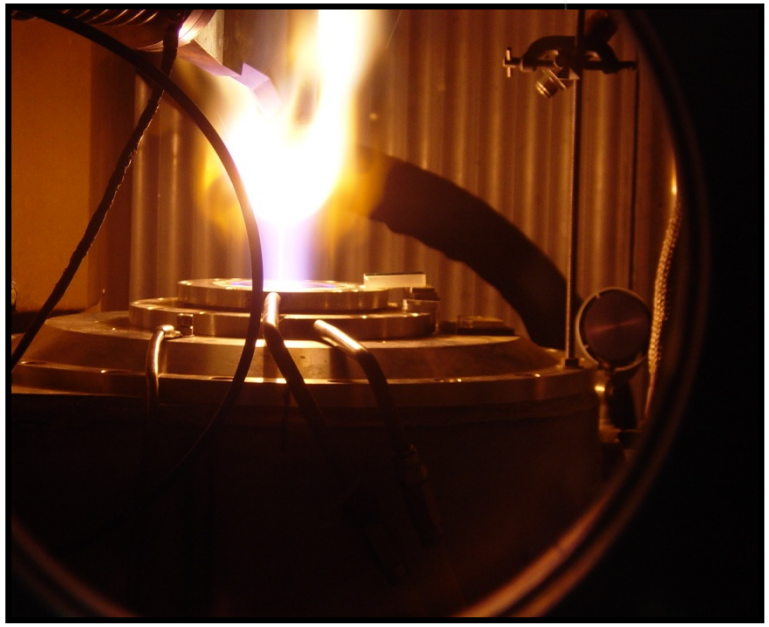
Plasma test : COMETE facility

- Stagnation point configuration
- 300 to 7000 kW/m^2
- Duration : few seconds to 30 minutes test
- Non polluted flow
- Air atmosphere





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Plasma test : Aerothermal environment

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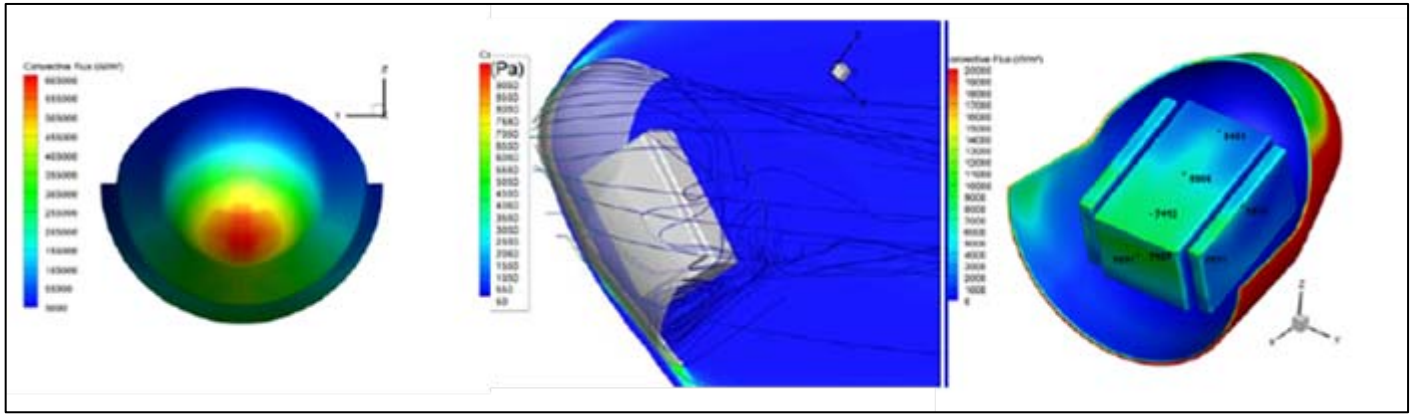
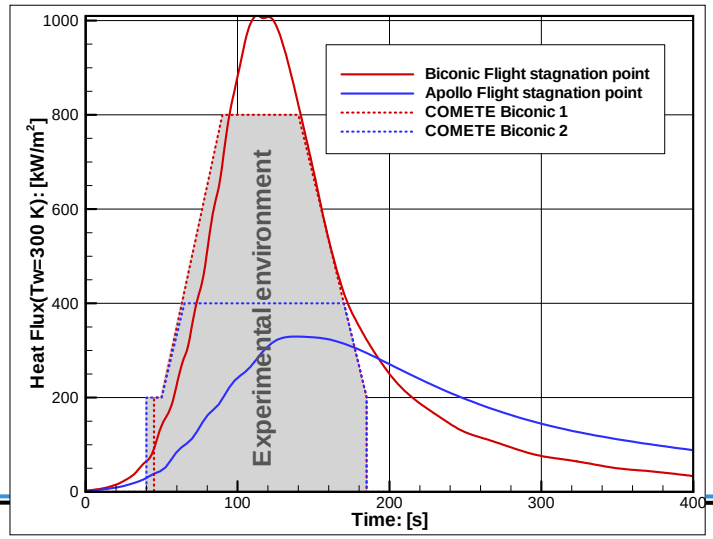
- 2 representative ground missions derived from maximum energy flight conditions :





COMETE Biconic 1

$$\varphi_{max} = 800\ kW/m^2$$

$$E_{max} = 84\ MJ/m^2$$

$$P \sim 100\ mbar$$

COMETE Biconic 2:

$$\varphi_{max} = 400\ kW/m^2$$

$$E_{max} = 53\ MJ/m^2$$

$$P \sim 100\ mbar$$

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Plasma test : First Results

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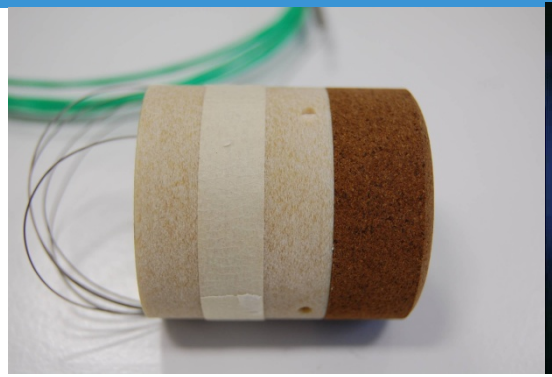
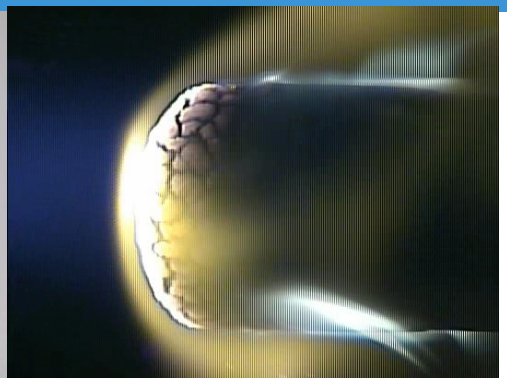
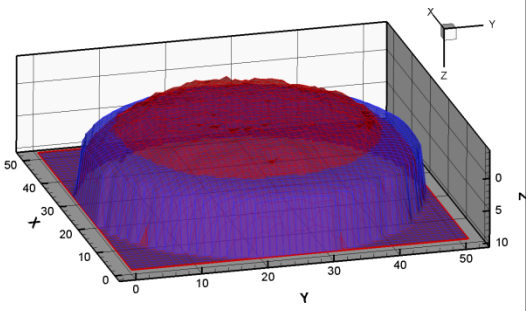
- Sample definition enabling:
  - Back face Temperature
  - Surface recession profile
  - Material mass loss

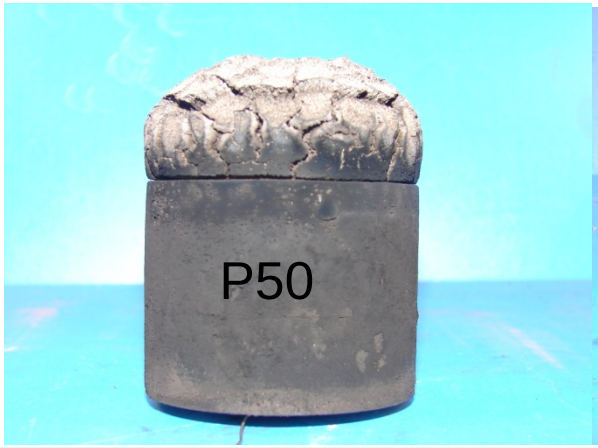




- Final selection of the most promising formulations based on thermal and integrity criteria



Before/after test NL profile



Comparison movie
NL-TPS3J

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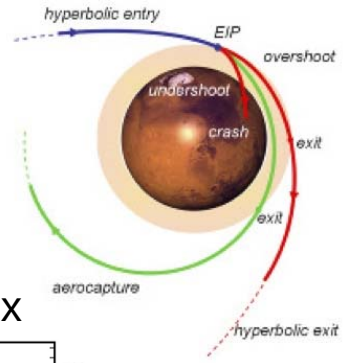
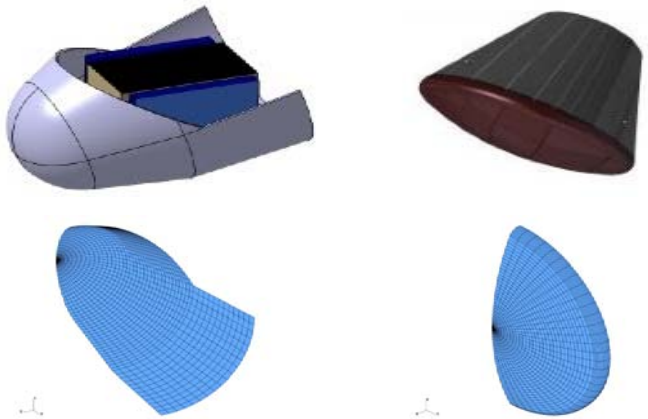
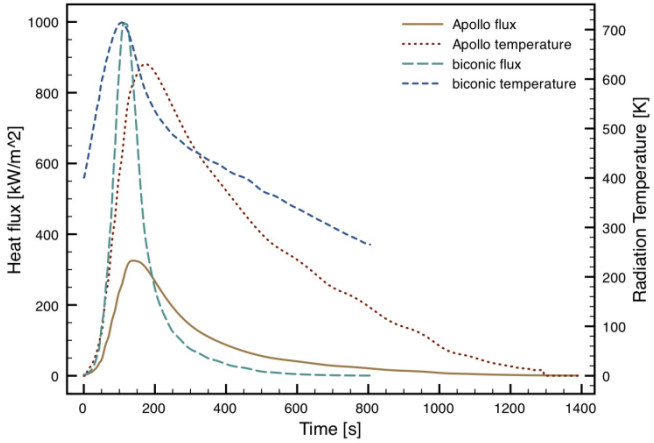
Spacecraft trade-off / flight environment

- Thermal analysis for aerocapture trajectory
- Maximum heat load trajectory (undershoot); dimensioning for support structure temperature
  - Radiation $$q = \varepsilon\sigma\left(T_R^4(t,\bar{x}) - T_w^4\right)$$
  - Convection $$q = q(t, T_w, \vec{x})$$
- Apollo like shape and biconic shape





Stagnation point heat flux



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1D thermal and ablative analysis

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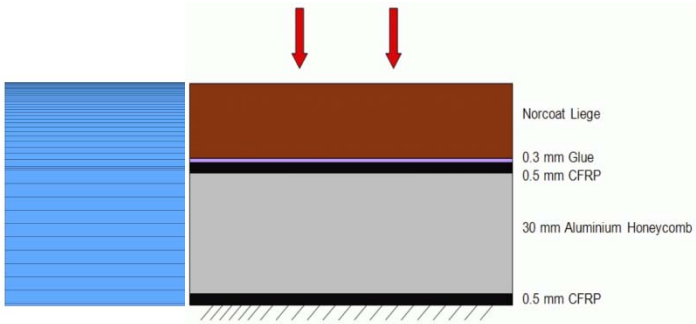
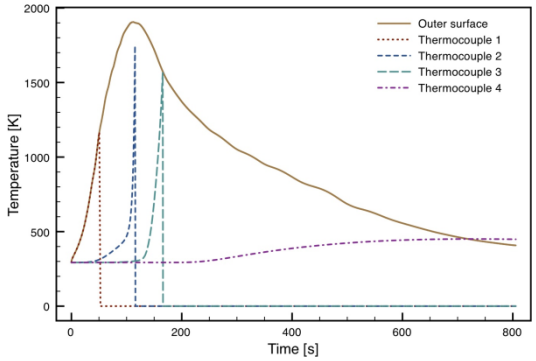
- Norcoat-Liège
  - Single specie Arrhenius law

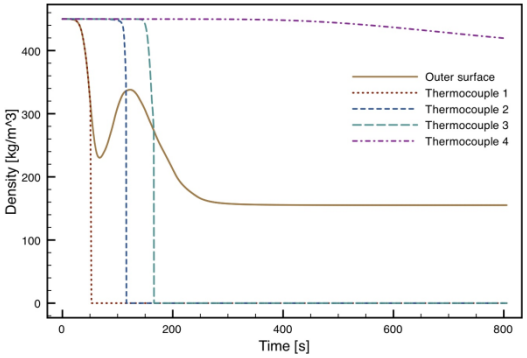
$$\dot{\rho} = -A\rho_v^{1-N}\left(\rho - \rho_c\right)^N e^{-E/R.T}$$

  - Heat-balance including
    - Pyrolysis heat $-H_p\dot{\rho}$
    - Gas transport $-\dot{\bar{m}}^g \nabla h^g$
  - Temperature dependent ablation speed $\dot{s} = \dot{s}\left(T_w\right)$



- 3D Finite element implementation in SAMCEF Amaryllis
- 1D results at different thermo-couple positions
  - Biconic stagnation point load
  - Fixed position TC's
  - "Loss" of signal
  - Ablation vs. pyrolysis speed





1D/3D thermal and ablative analysis

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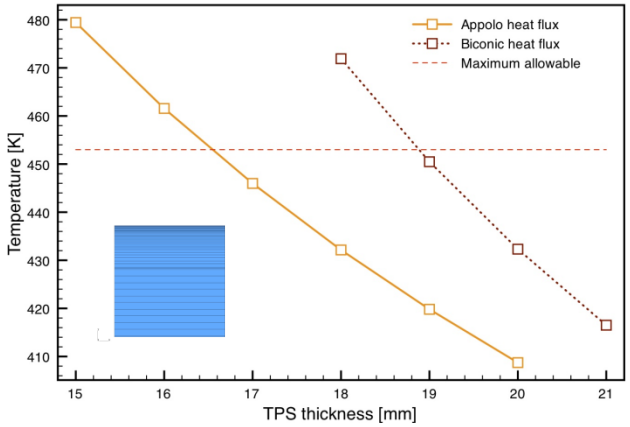
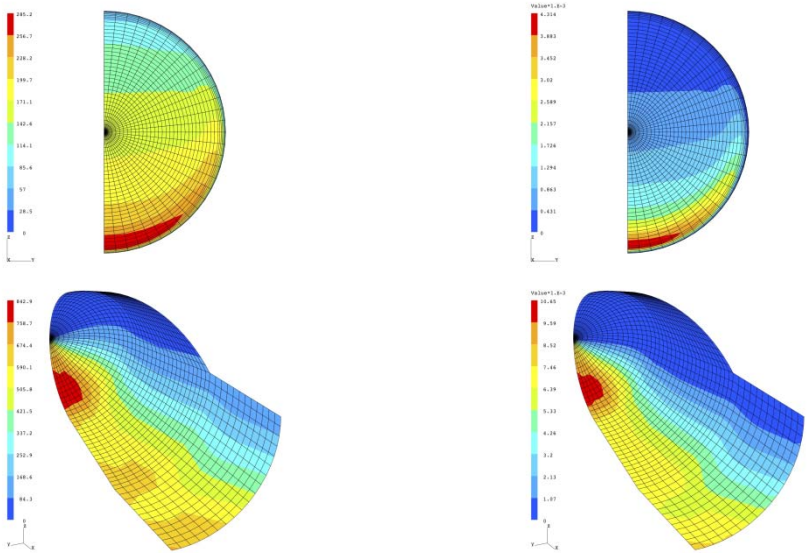
- 1D TPS thickness calculation
  - Stagnation point load
  - Maximum allowable support temperature (180 °C)
    - Apollo like shape: 17 mm
    - Biconic shape: 19 mm



- 3D models
  - Constant thickness TPS
  - Same support structure
  - Apollo
    - Heat flux 245.2 kW/m^2 (t = 149 s)
    - Final ablation: 4 mm
  - Biconic
    - Heat flux 842.9 kW/m^2 (t=112 s)
    - Final ablation: 10 mm



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3D thermal and ablative analysis

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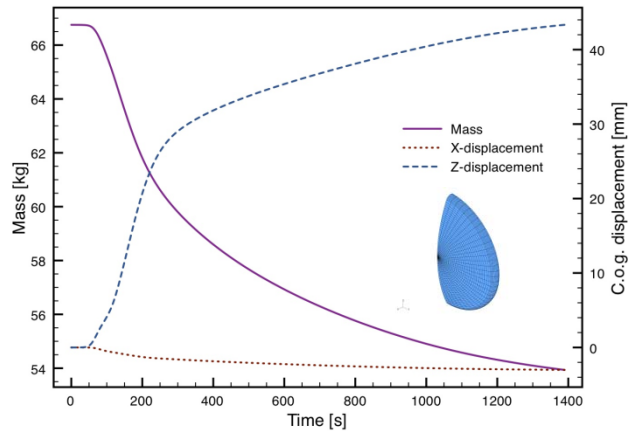
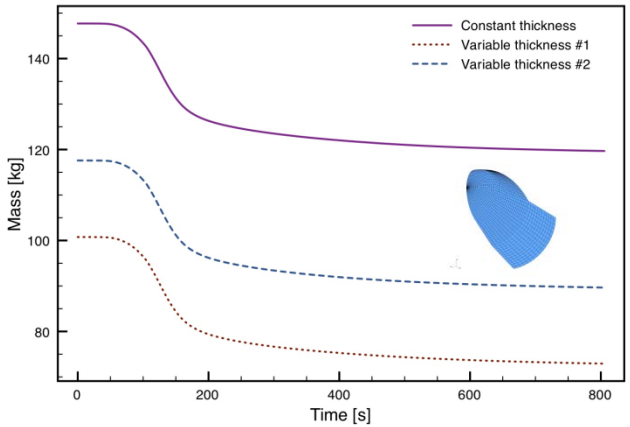
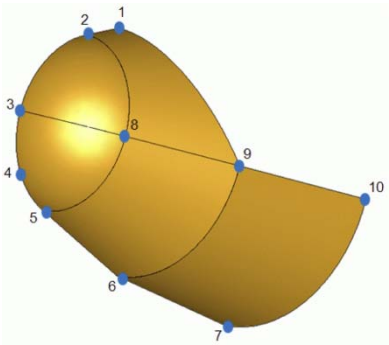
- Four heat-shields
  - Apollo like shape
    - Constant thickness (17 mm)
    - Mass 133.5 kg, mass loss 25.6 kg
    - 144.131 doff CPU 13 h 43 m (422 time steps)
  - Biconic heat shield
    - Constant thicknesses (19 mm)
      - Outside mass budget
    - 2 variable thicknesses
      - Initial design incorrect
    - 190.448 doff CPU 29 h 30 m (598 time steps)







Point number	S/D [-]	ϕ [°]	TPS #1 [mm]	TPS #2 [mm]
1	0.520	0.00	6	**8**
2	0.381	0.00	6	**8**
3	0.000	180.0	15	15
4	0.212	180.0	19	19
1	0.381	180.0	16	**19**
6	0.798	180.0	16	16
7	1.325	180.0	16	16
8	0.381	90.0	8	**10**
9	0.798	90.0	8	**10**
10	1.325	90.0	7	**10**

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3D thermal and ablative analysis

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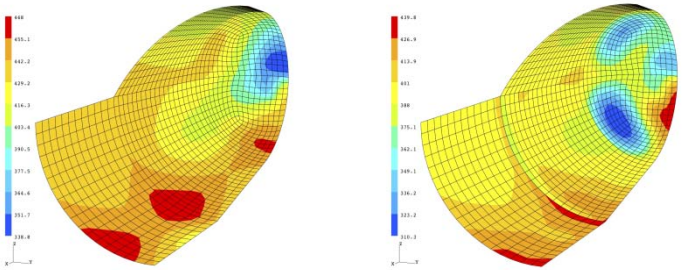
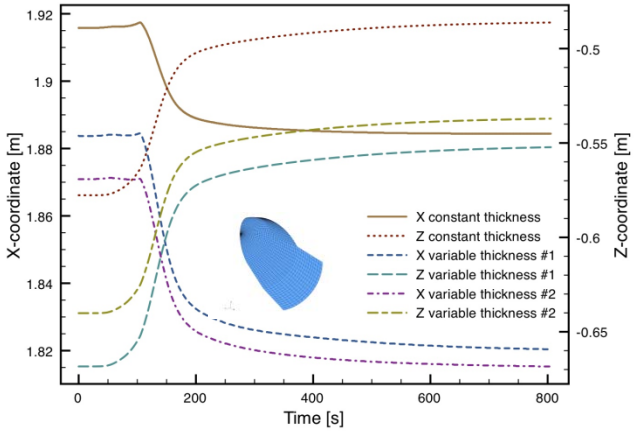
- Variable thickness biconic
  - Linear interpolation of thickness between points
  - Inner temperature at end of trajectory
    - TPS #1: maximum 468 K
    - TPS #2: maximum 439 K
  - Geometry update procedure not optimal



- C.o.g position for Biconic
  - Z-coordinate moves upward
  - X-coordinate moves backward before moving forward
    - Stabilizing effect pitching moment
    - Ablation has largest contribution to mass loss



- Design constraints
  - Mass budget 260 kg
  - 1-2 % max. relative c.o.g. change
    (based on max heatshield diameter)

Heat Shield	Mass [kg]	Mass-loss [kg]	$\frac{x_{c.o.g.}}{D}$ [%]	$\frac{z_{c.o.g.}}{D}$ [%]
Apollo	133.5	25.6	-0.083	0.12
Const. thickness	295.4	56.1	-0.88	2.54
Var. thickness #1	201.6	55.8	-1.76	3.20
Var. thickness #2	235.1	55,8	-1.55	2.86

Conclusion

- Ways for enhancement have been demonstrated
  - Reinforced and lighter solutions demonstrated promising behaviour under near aerocapture thermal environment
- Synthesis phase
  - Tests results analysis
  - Trade-off
- Demonstrator manufacturing
  - Molding of a scale prototype of the whole front heat shield
  - Representative thickness to assess manufacturing issues.
  - Integrated TPS measurements (Tc, recession sensors)
- A 3D charring/ablation code has been implemented and tested
- A first sizing of a 3D TPS has been successfully performed
- AEROFAST to be continued ?

THANK YOU
FOR YOUR ATTENTION

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