ONERA
THE FRENCH AEROSPACE LAB
r e t u r n   o n   i n n o v a t i o n

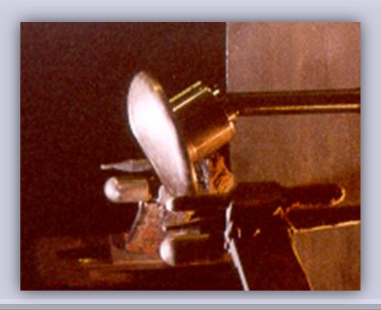
Mars Aerocapture Technique: Aerothermodynamic Issues

Gillian Leplat[1], Jean-Luc Vérant[1] & Jean-Michel Lamet[2]

[1] ONERA – The French Aerospace Lab – F-31055 Toulouse, France
[2] ONERA – The French Aerospace Lab – F-92322 Châtillon, France

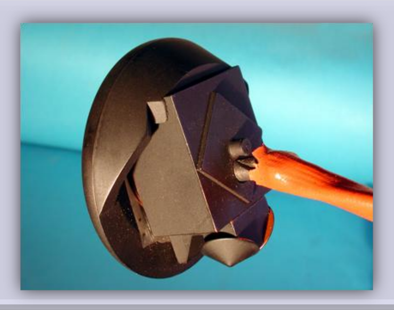
MARS PREMIER BACKGROUND EXPERIENCE

1999 – Mars Premier CNES/NASA project



ONERA with CNES addressing Mars aerocapture ATD of MSRO vehicle (AOTV-like heatshield)

2000 – Backside shear layer interaction investigation



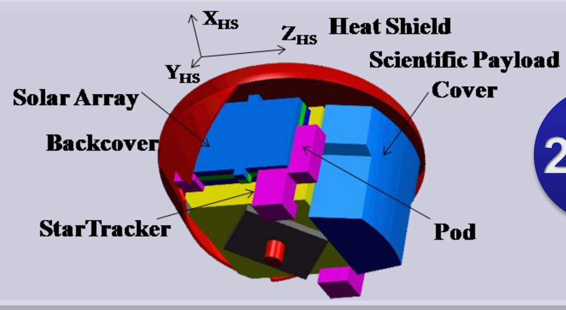
Partial back cover systems to prevent critical convective payload heating

Evolutive design from generic to industrial orbiter

2002 – Radiative heating assessment on symplified axisymmetrical geometry

Critical radiative heating on the afterbody (up to ~10% of stagnation heat flux)
Highest convective-over-radiative ratio at the exit point of trajectory

2003 – End of Project



Final configuration with industrial payload and equipments

AEROFAST EU RESEARCH PROGRAM (2008 - 2011)

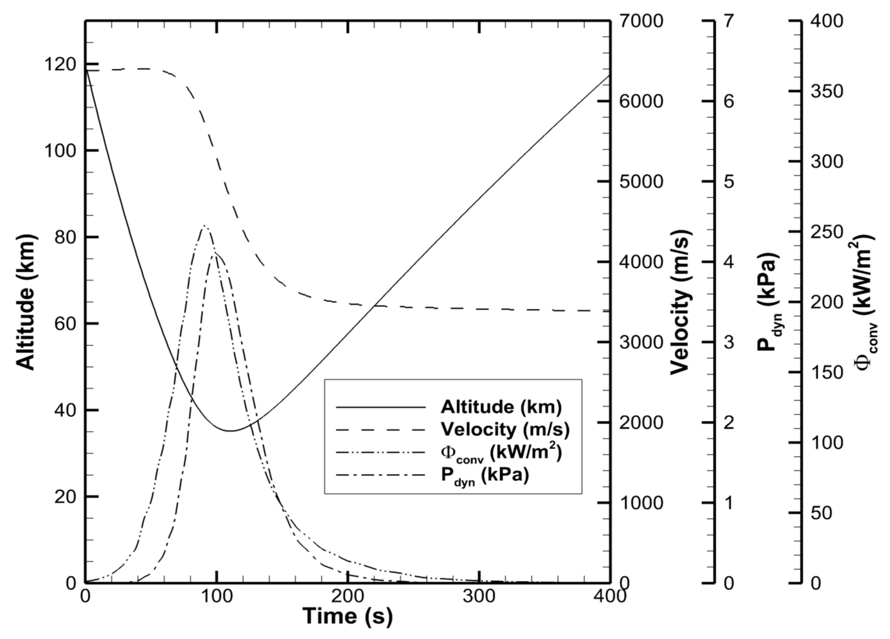
Aerocapture Maneuver

- New technique for planetary exploration
- Single pass through the atmosphere to slow down the spacecraft and achieve targeted orbit
- 30-50% mass saving at launch with respect to conventional propelled aerobraking ⇨ 82% of initial mass put into final orbit

Innovative Open Sphero-biconic Heatshield

- R_N = 1.123m ; θ_1 = 20 ; θ_2 = 7 ; length = 4.032m ; diameter = 3.6m
- Lift-over-drag ratio C_L/C_D ~ 0.4
- Easy jettisoning and significant mass saving compared to Apollo-like capsules
- Longitudinal and lateral static stability compliant with GNC capabilities
- 40 trim angle of attack

Aerocapture undershoot trajectory

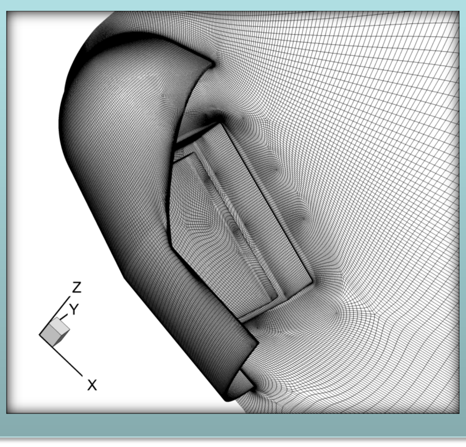


Flow conditions along characteristic trajectory points

Trajectory point	Maximum heat flux	Maximum dynamic pressure	Exit point
ρ (kg.m⁻³)	2.86 x 10⁻⁴	2.25 x 10⁻⁴	2.12 x 10⁻⁴
V (m.s⁻¹)	5711	5355	3490
P (Pa)	8.58	6.73	0.65
Mach	29	27.1	17.4
T (K)	156.1	156.8	161.23

AEROSHAPE DESIGN THROUGH ACCURATE AEROTHERMODYNAMIC COMPUTATIONS

CELHyO3D ATD Solver



Reactive gas model
- CO_2 Mars atmosphere
- 5 species model:
  - *CO_2 – CO – O_2 – C – O*
- chemical non equilibrium
- 18 reaction chemistry Park model

Boundary conditions
- Mars upstream flow: 100% CO_2
- Super-catalytic heatshield and payload walls (complete recombinaition of CO_2 at the wall)
- Isothermal walls (1000K on the shield and 500K on the payload)

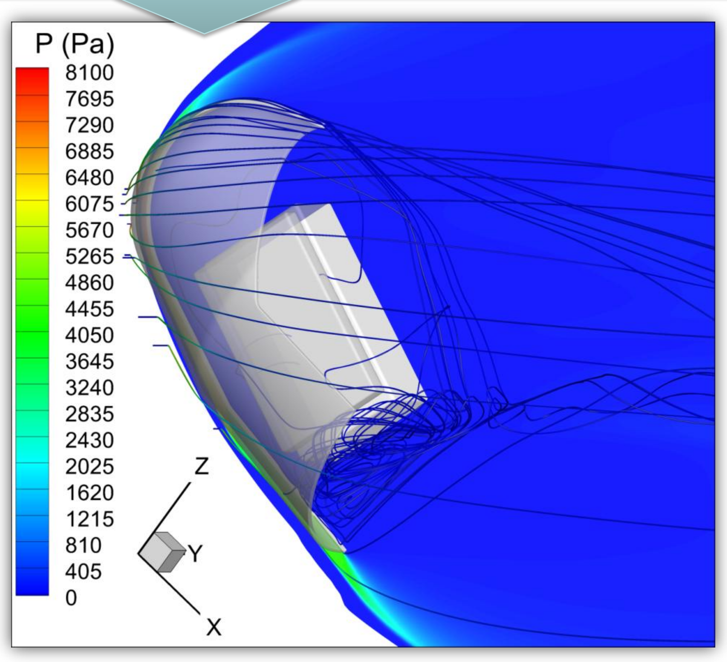
Grid generation
- Multi-block structured grid
  - *1499 blocks*
  - *9 million cells*
- Convergence carried out on 3 levels of refinement:
  - *coarse ⇨ medium ⇨ fine*
- First cell height: 1µm

Numerical methods
- Grid adapted to the inflow shock to avoid spurious oscillations and preserve clean heating wall mappings
- Hybrid Upwind Scheme
  - *Oscher approach for accurate wall heating*
  - *Van Leer approach in strong hypersonic shock regions*

ASTRE Radiative Solver

Monte Carlo forward method – Statistical approach ⇨ Narrow Band Statistical Model – Radiative properties of CO_2/CO in infrared spectrum ⇨ Projection of ATD results onto a 500,000 cell grid ⇨ Ray tracing ⇨ non uniform spatial distribution – 2,560 rays to achieve convergence

Aerodynamic analysis



Pressure distribution in the symmetry plane and streamlines for the maximum dynamic pressure flow conditions

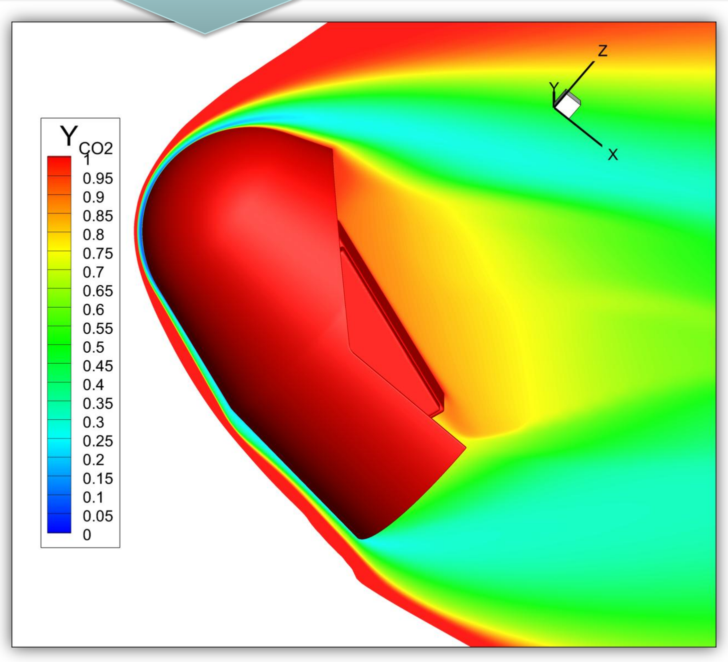
Aerodynamic performances

- High pressures remain confined on the heatshield centerline in the windward side and the leeward side only experience low pressures close to the inflow conditions
- C_L/C_D = 0.4 at α=40 confirmed by the computations

Wake flow

- 40 trim angle leads to aerodynamic protection of the top of the satellite
- Wake closure occurs after the payload and moves downstream until the end of the aerocapture maneuver
- Interaction between the wake flow and the payload located rather at the rear the satellite with formation of a large recirculation zone

Chemical Nonequilibrium



CO_2 mass fraction distribution in the symmetry plane, shield and payload surfaces for the maximum heat flux flow conditions

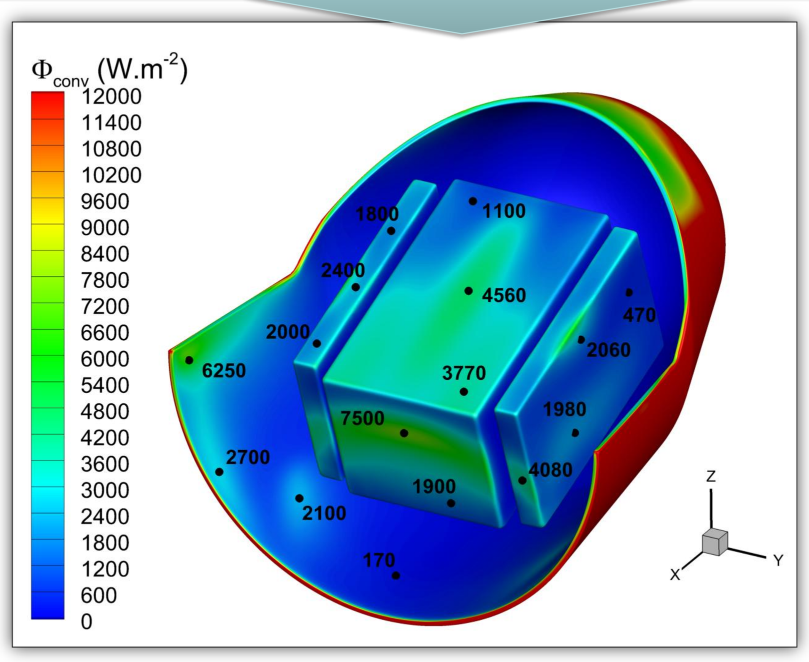
CO_2 chemical nonequilibrium

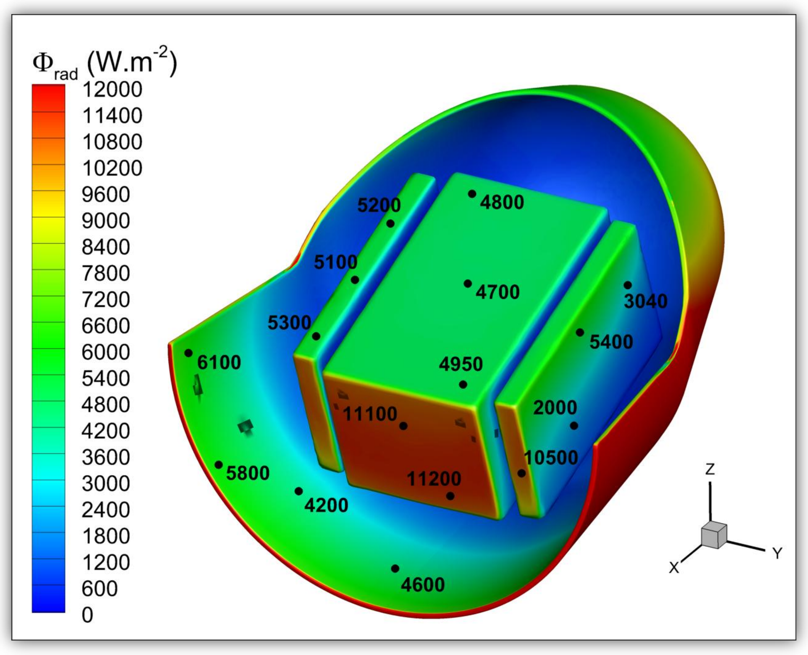
- CO_2 molecule highly dissociated for the maximum heat flux and maximum dynamic pressure conditions
- Chemical relaxation results in a gas mixture composition at the stagnation point:

CO_2	CO	O_2	O
20%	50%	10%	20%

(atomic C is still minority)
- This chemical status will drive the radiative heat transfer processes in the infrared spectrum range of interest
- 1% CO_2 dissociation at the exit point

Prediction of Heat Transfer on the Spacecraft Walls





Spacecraft heat flux distribution for the maximum heat flux trajectory point (left: convective – right: radiative contributions)

Heatshield

- Maximum convective heating at the stagnation point region (590kW.m⁻²)
- Maximum radiative heat flux on the second conical part of the shield where the shock gas layer is thick, dense and hot with relatively high mass fractions of CO_2 and CO molecules

Payload

- Maximum convective heating at the rear due to strong recirculation zone
- Maximum radiative heat flux also located at the rear of the payload caused by the hot shear layers which radiates backwards in a privileged way (high view factors)
- Highest convective-over-radiative ratio experienced at the exit point of the aerocapture trajectory as already noticed during Mars Premier program in 2002
- <u>More than 20kW.m⁻² of global heating non compatible with opened configuration</u>

Trajectory point	Maximum heat flux		Maximum dynamic pressure		Exit Point	
Φ_{conv} max (kW.m⁻²)	590	[7.5]	530	[7.2]	48	[0.4]
Φ_{rad} max (kW.m⁻²)	34	[11.5]	38	[13.7]	2.8	[0.8]
Ratio rad/conv (%)	5.8	[153]	7.1	[190]	5.8	[200]

Convective and radiative heat flux comparison (maximum values on the heatshield [and on the rear side of the payload])