Radiation-Shapes-Thermal Protection Investigations

for High Speed Earth Re-entry

RASTAS SPEAR : Radiation-Shapes-Thermal Protection Investigations for High Speed Earth Re-entry

9th International Planetary Probe Workshop - Toulouse, France 2012, June 2-4 - Session 6B "Earth entry and Sample Return"

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Overview

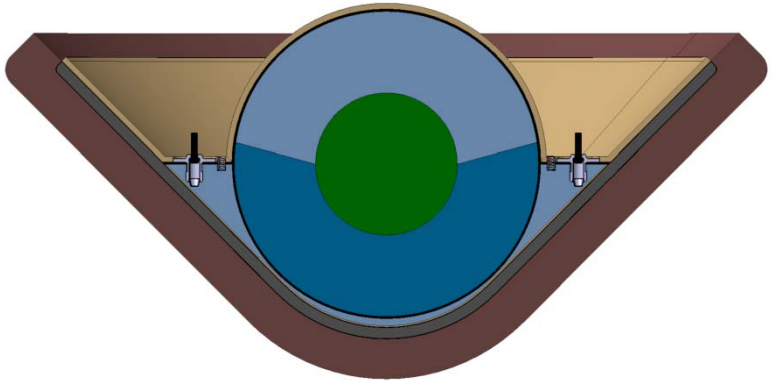
- Introduction
  - Objectives
  - WBS
- Overview of technical activities
  - Review of System Requirements
  - Ground Facilities Improvement
  - Key Technologies for High Speed Entry
  - Ablation – flight mechanics coupling assessment
  - Gas-surface interactions modeling
- Next Steps / Conclusion

General Objective

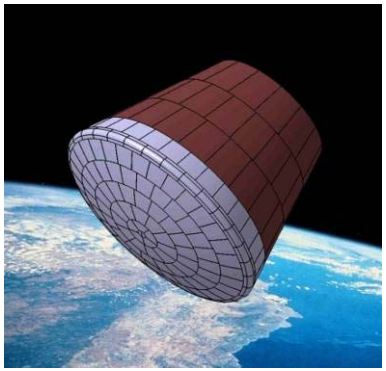
- Sample Return Missions : an important step for Solar System Exploration
  - After collecting samples, any return mission will end by high-speed re-entry in Earth's atmosphere.
  - This requires strong technological bases and a good understanding of the environment encountered during the Earth re-entry.

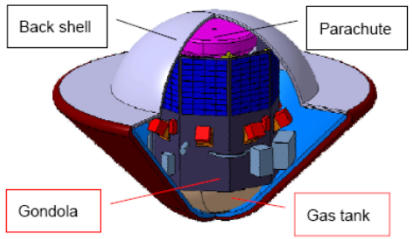
- Investment in high speed re-entry technology development is thus appropriate today
- to enable future planetary exploration missions in the coming decades.
  - Phobos Sample Return, Marco Polo, …, Mars Sample Return

→ Rastas Spear project
  - to increase Europe's knowledge in high speed re-entry vehicle technology



Main focus : Sample Return Capsule





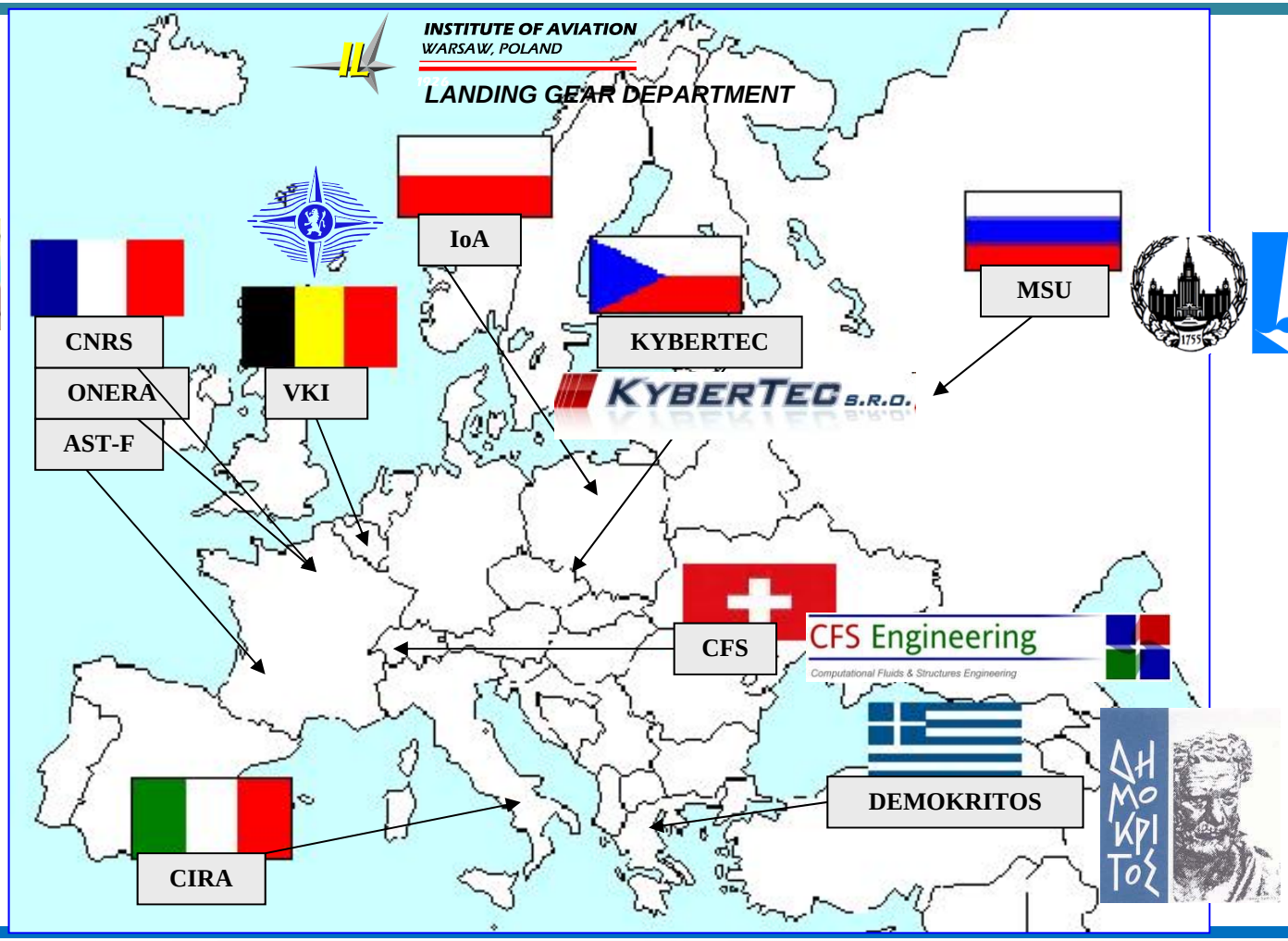
Other potential applications : ARV, Venus

Introduction /Acknowledgement

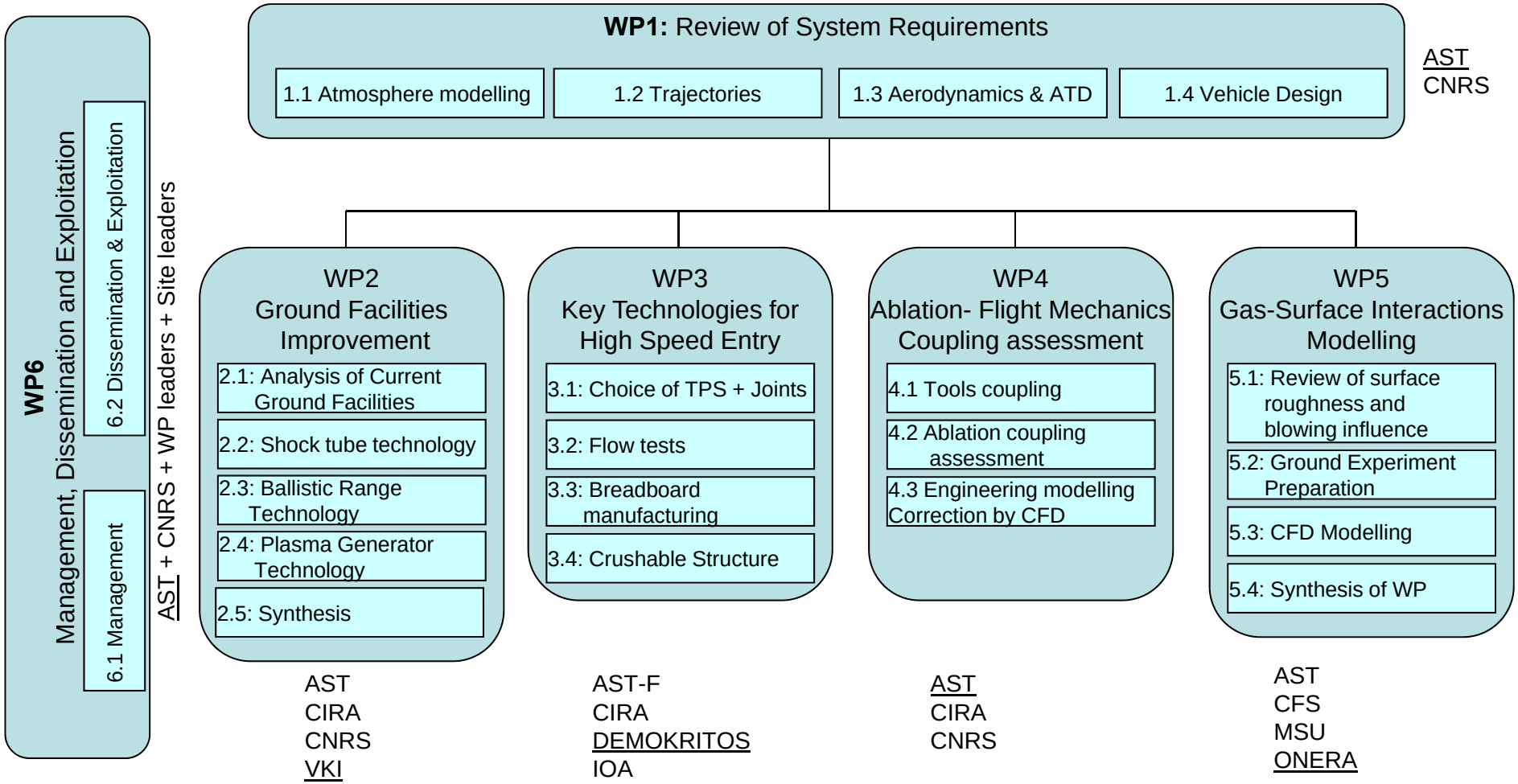
- In the frame of EC FP7 second call
  - Activity 9.2 – strengthening of space foundations / research to support space science exploration
  - SPA.2009.2.1.01 Space Exploration
- Duration
  - Sep 2010 - Sep 2012 (*)
    (*)+ tbd extension
- Status :
  - Team composed of 10 partners
  - Astrium is the coordinator
- Budget
  - total : 2.3 M€
  - including 1.6 M€ EU grant
- More at www.rastas-spear.eu

SEVENTH FRAMEWORK PROGRAMME

10 partners from 8 European countries



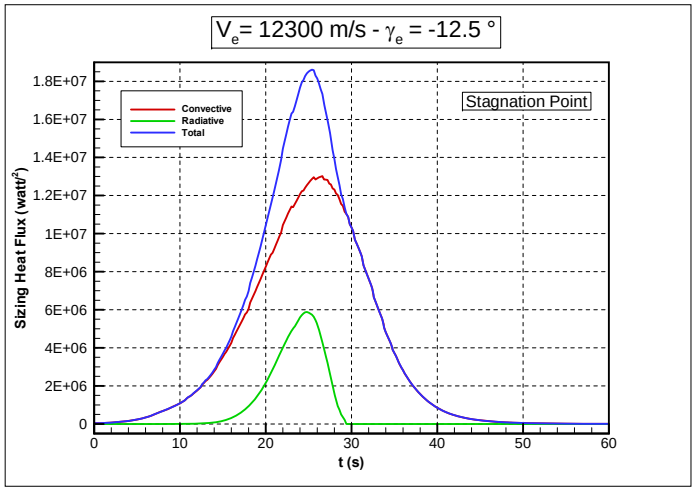
WBS


WP6
Management, Dissemination and Exploitation
6.1 Management
6.2 Dissemination & Exploitation
AST + CNRS + WP leaders + Site leaders
WP1: Review of System Requirements
1.1 Atmosphere modelling
1.2 Trajectories
1.3 Aerodynamics & ATD
1.4 Vehicle Design
AST
CNRS
WP2
Ground Facilities Improvement
2.1: Analysis of Current Ground Facilities
2.2: Shock tube technology
2.3: Ballistic Range Technology
2.4: Plasma Generator Technology
2.5: Synthesis
AST
CIRA
CNRS
VKI
WP3
Key Technologies for High Speed Entry
3.1: Choice of TPS + Joints
3.2: Flow tests
3.3: Breadboard manufacturing
3.4: Crushable Structure
AST-F
CIRA
DEMOKRITOS
IOA
WP4
Ablation- Flight Mechanics Coupling assessment
4.1 Tools coupling
4.2 Ablation coupling assessment
4.3 Engineering modelling Correction by CFD
AST
CIRA
CNRS
WP5
Gas-Surface Interactions Modelling
5.1: Review of surface roughness and blowing influence
5.2: Ground Experiment Preparation
5.3: CFD Modelling
5.4: Synthesis of WP
AST
CFS
MSU
ONERA

WP 1 results: Review of System Requirements

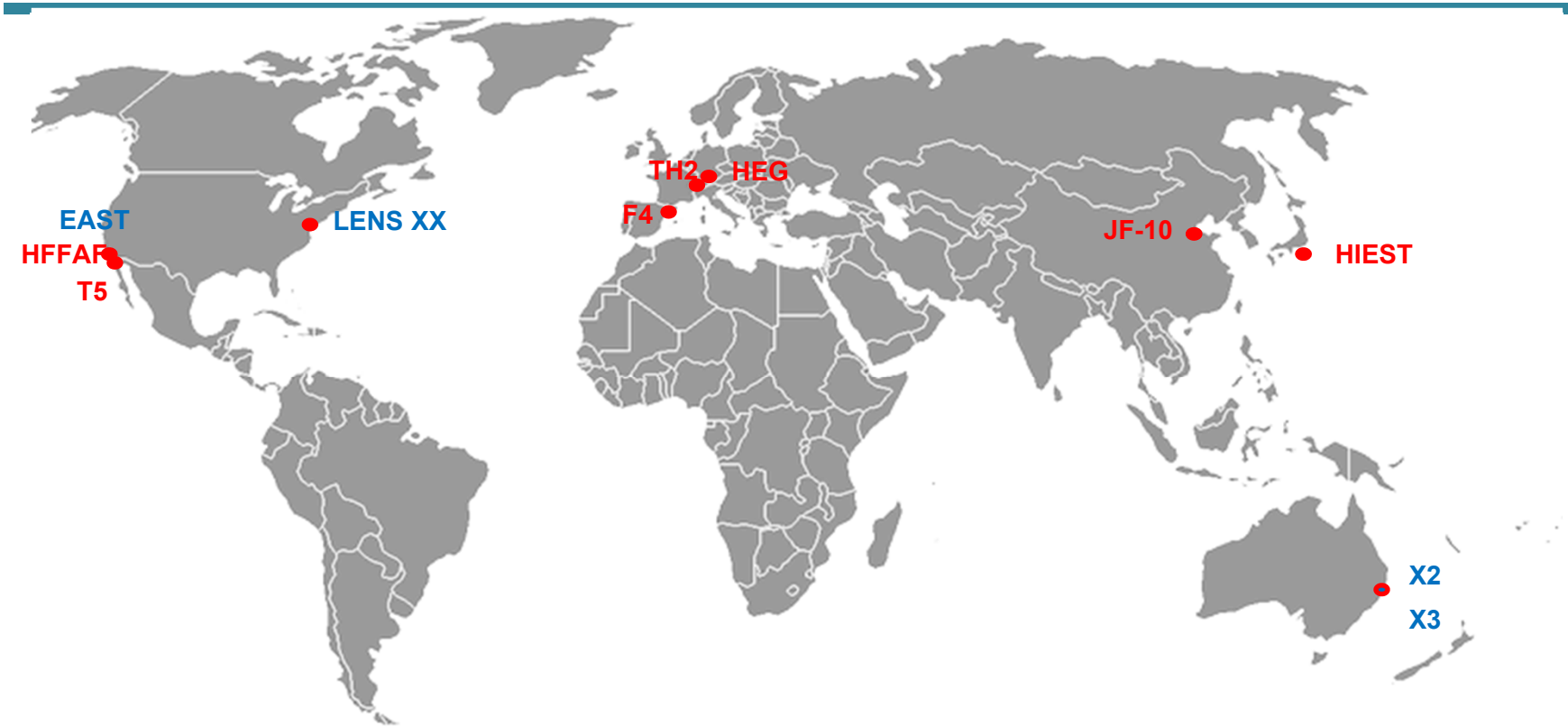
- WP 1.1: Atmosphere modelling
  - Atmosphere compositions for Earth and Venus,
- WP 1.2: Trajectories
  - Identification of generic aeroshapes with respect to candidate exploration missions.
    - Investigation focused on Earth entry,
  - Flight domain determined with constraints on:
    - max heat flux, max heat load, max g-load
- WP 1.3: Aerodynamics & Aerothermodynamics
  - Convective and radiative heat flux
- WP 1.4: Vehicle design
  - Preliminary design of the generic capsule, and determination of TPS thickness
    - Definition of the Mass Centering and Inertia (MCI)
  - Preliminary TPS related requirements for other WP : surface recession, mass loss, temperature evolution, gas flow rate,…

→ See details on IPPW8 poster and paper



Sphere cone 45°
Diameter D =1100 mm
Nose radius Rn = 275 mm
Mass m = 46.6 kg

D2.1 : Review on High Enthalpy Facilities

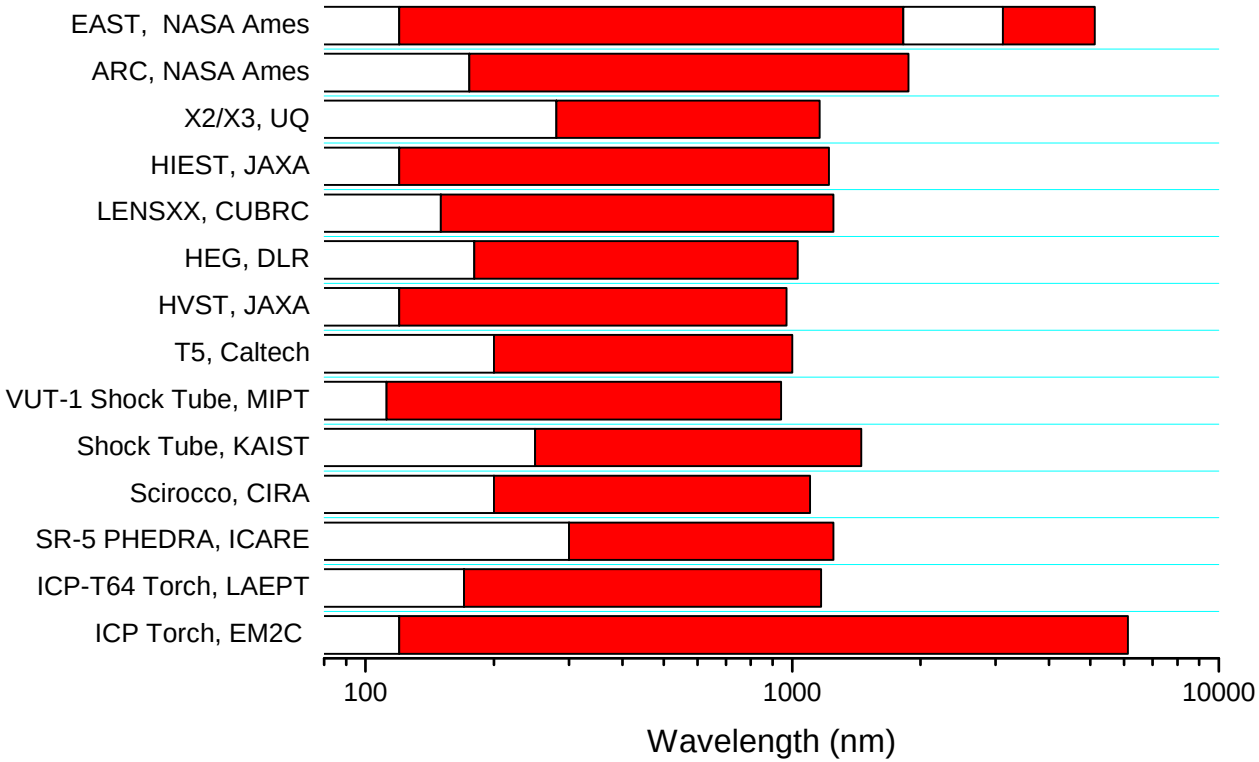


Only few facilities (in blue) are able to duplicate super orbital reentry conditions

D2.2 Ground Facilities for Radiation Studies

→ *Review on Spectroscopy Instrumentation*

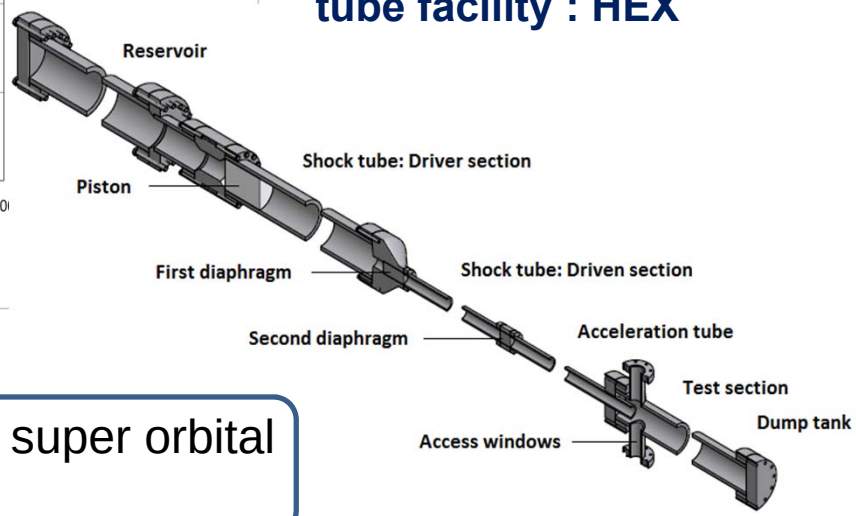
Wavelength range of dedicated instrumentation for high enthalpy and plasma facilities



→ All tools are operational to build-up radiation databases

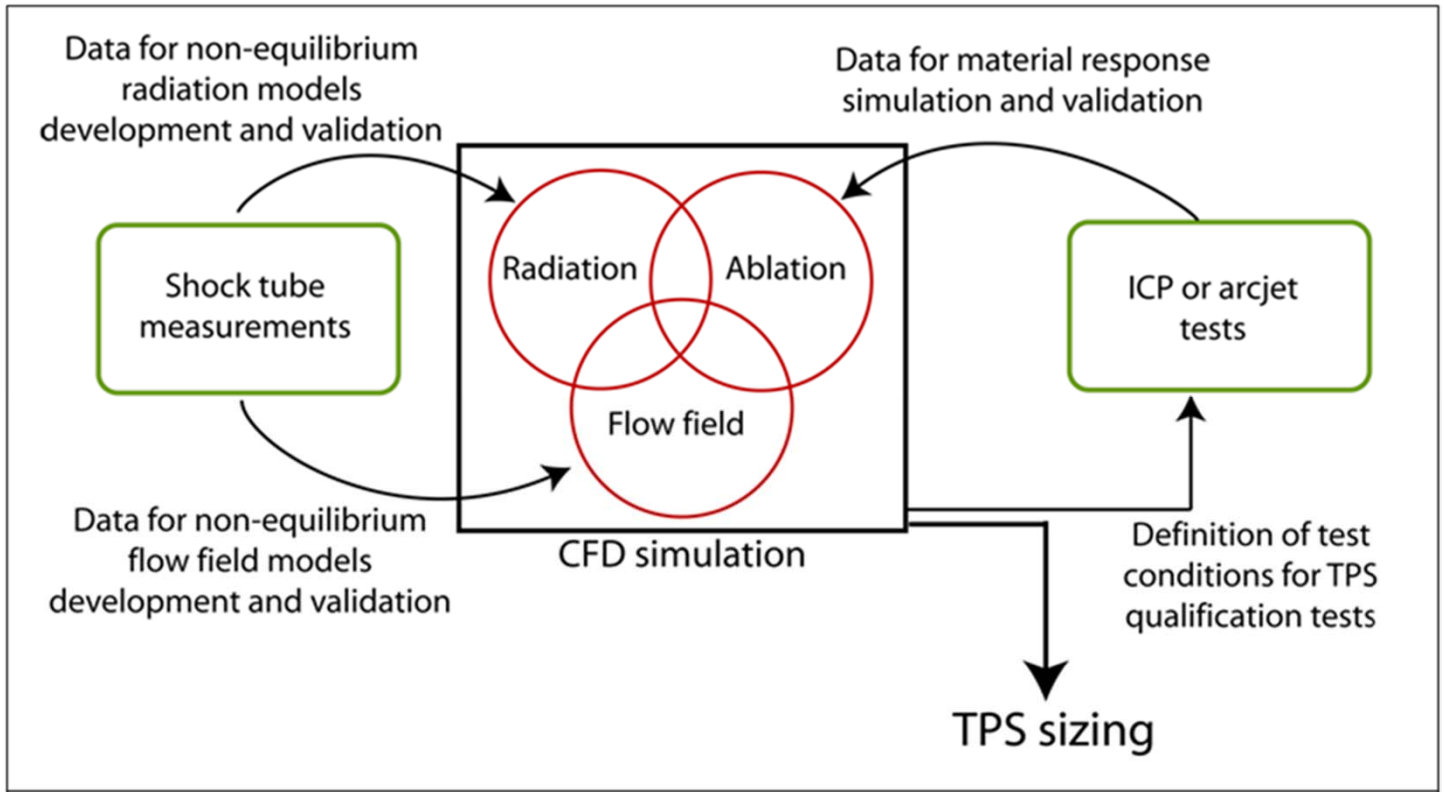
D2.4 Synthesis
Pre-design of hyper velocity facilty

Preliminary design for an high Enthalpy Expansion tube facility : HEX



→ The designed facility targets duplication of super orbital testing condition

D2.4 Synthesis
Testing strategy for super-orbital reentry



The testing strategy involved hyper velocity facility together with plasma wind tunnel to developed radiation and GSI models to be coupled with CFD tools.

WP3: Key Technologies for High Speed Entry

WP3.1 : choice of TPS + joints

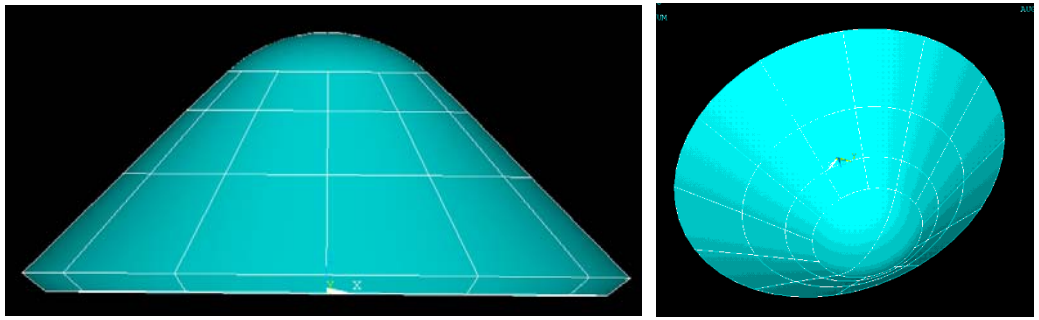
- **Based on ASTERM material**
- **Elaboration of a relevant set of criteria**
- **Screening of adhesives**
  - **→ 2 products compared with ref CV1142**
- **Elementary characterisation**
  - **(shear, bending, tensile)**

WP3.2

- **Manufacturing of samples for testing on Scirocco**
- **Then analysis of the tests results**

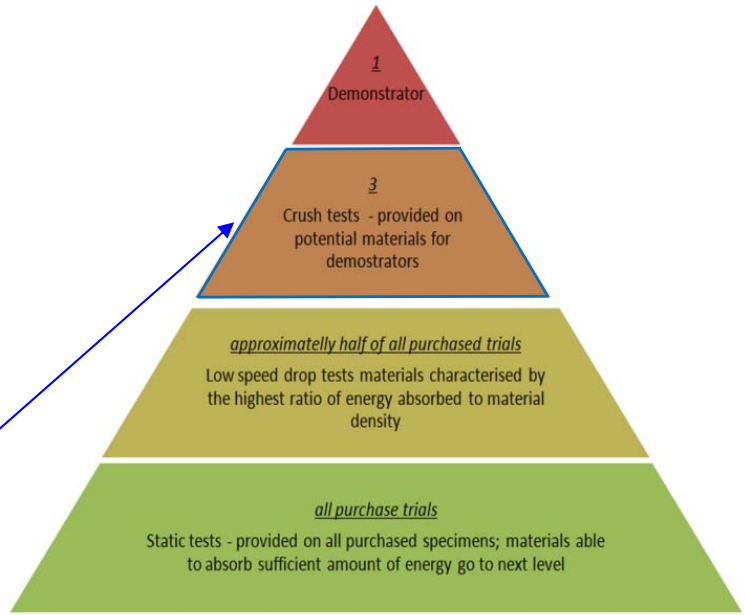
WP3.3

- **Manufacturing of a demonstrator**



WP3.4. Crushable Structures General overview

- Main task of the research: developing methodology for selection and evaluation of energy absorbing material based on numerical simulations coupled with simple shape specimens impact tests
- Selection of energy absorbing material for max. acceleration approximately 2000 g
- Based on static and dynamic tests, developing methodology for selection energy materials under defined requirements
- Current stage of research



WP3.4 Preparation

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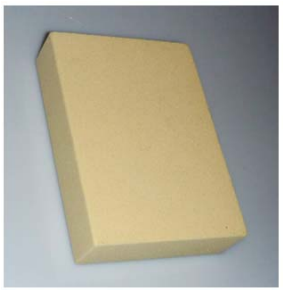
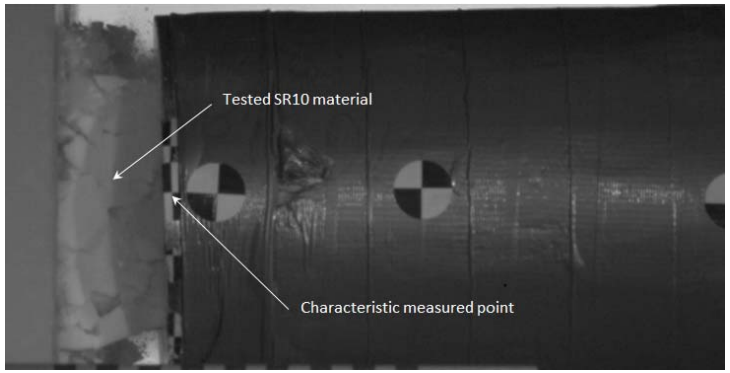
- ✓ Air canon calibration and testing using 1.6 kg bullet
- ✓ First-stage high-speed camera tests for finding optimal experiment setup
- ✓ Final energy absorbing materials selection for second-stage test



SR10

CELL10



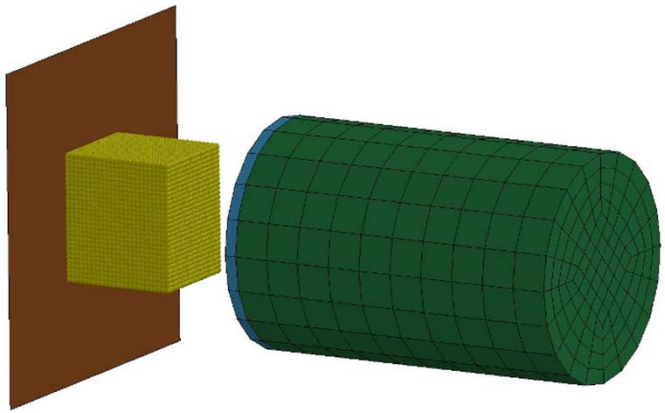
WP3.4 Achievements

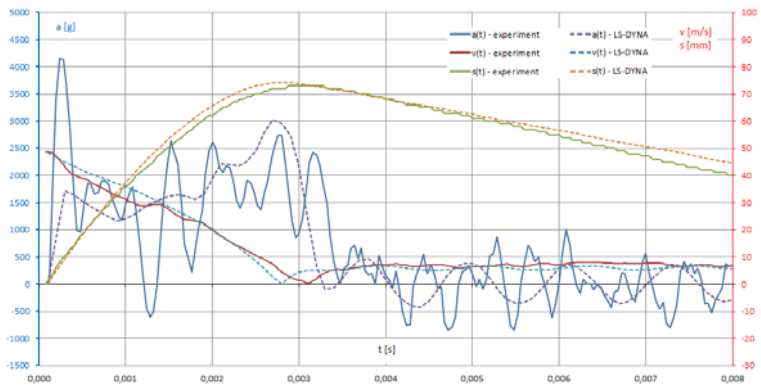
Evaluation methodology:

- Static tests for energy absorbing materials to obtain stress-strain characteristics
- Dynamic numerical simulations using static experimental data
- Numerical simulations data evaluation and calibration using dynamic experimental impact tests

Current stage of research

- Improved numerical SPH and FEM LS-DYNA model for testing crushable foam materials
- Final calibration for impact tests (high-speed camera settings, lighting, position etc.)
- Good correlation between numerical and experiment data numerical SPH and FEM LS-DYNA





Comparison of experiment and numerical data for SR10 material

WP3.4 Anticipated tasks before completion

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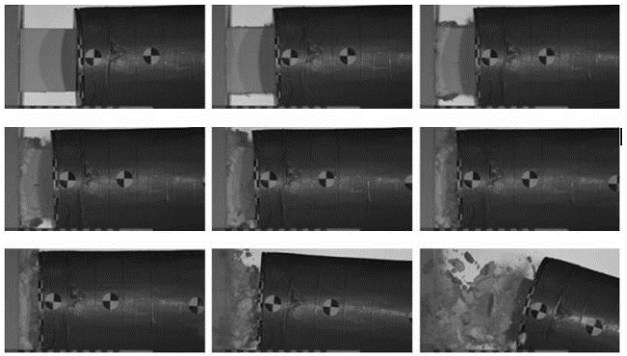
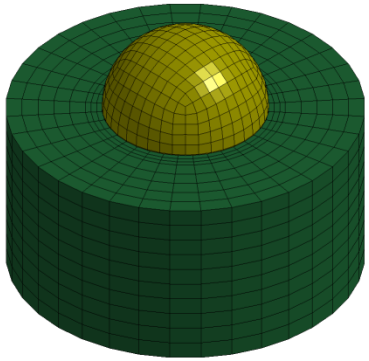
- ✓ Full-scale impact test of chosen material for: bullet mass m=5 [kg]
  - impact velocity v= 45 [m/s]
  - material thickness t = 0.115 [m]
- ✓ Test data analysis and comparison with numerical simulation





WP4: Ablation – flight mechanics coupling assessment Main Objectives

Based on WP1 results as inputs : flight environment, vehicle configuration

- **1- To assess impact of massive ablation on aerodynamic performances and stability along the entry trajectory path.**
- **2- To identify recession level that could be tolerated with respect to capsule aerodynamic performances and stability requirements.**
- **3- To elaborate and validate an engineering tool that couples:**
  - **Aeroshape aerodynamic,**
  - **Trajectory and stability,**
  - **Aerothermal environments,**
  - **TPS material thermal response**
  - **and then recession determination resulting in aeroshape modification.**
- **4- To translate these results into criteria for maximum recession requirements in relation with usual landing accuracy, g-loads, heating and incidence profile issues.**

WP4: Ablation – flight mechanics coupling assessment

Work logic:

WP4.1 – Tools Coupling (AST)
Coupling of following tools:

- Ablation & thermal TPS response code including Aeroshape modification
- Shock shape & - Pressure distribution & - Aerodynamic coefficients determination by CFD code, including ablation gas products injection
- 6 DoF Trajectory Tool

WP4.3 – Engineering modelling
Correction by CFD (AST – CIRA - CNRS)

- Assessment of Aeroshape modification (CIRA)
- Assessment of Radiation (CIRA-CNRS)
- Assessment of Surface mass blowing (CIRA)
- Development of engineering tool to determine radiating heating vs. recession rate (AST)
- Engineering correlation derivation from CFD computations (AST)

WP4.2 – Tools Coupling Assessment (AST)

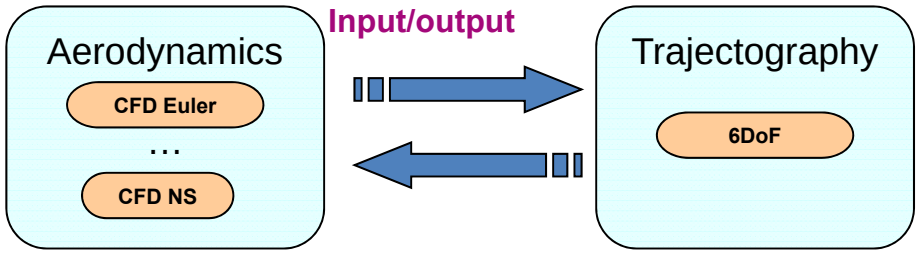
- Assessment of Ablations-flight mechanics effects for candidate Earth Entry capsule
- Sensitivity to TPS ablative properties
- Identification of requirements for maximum TPS recession

Synthesis (AST)

WP 4.1 – Tools coupling

Main requirements:

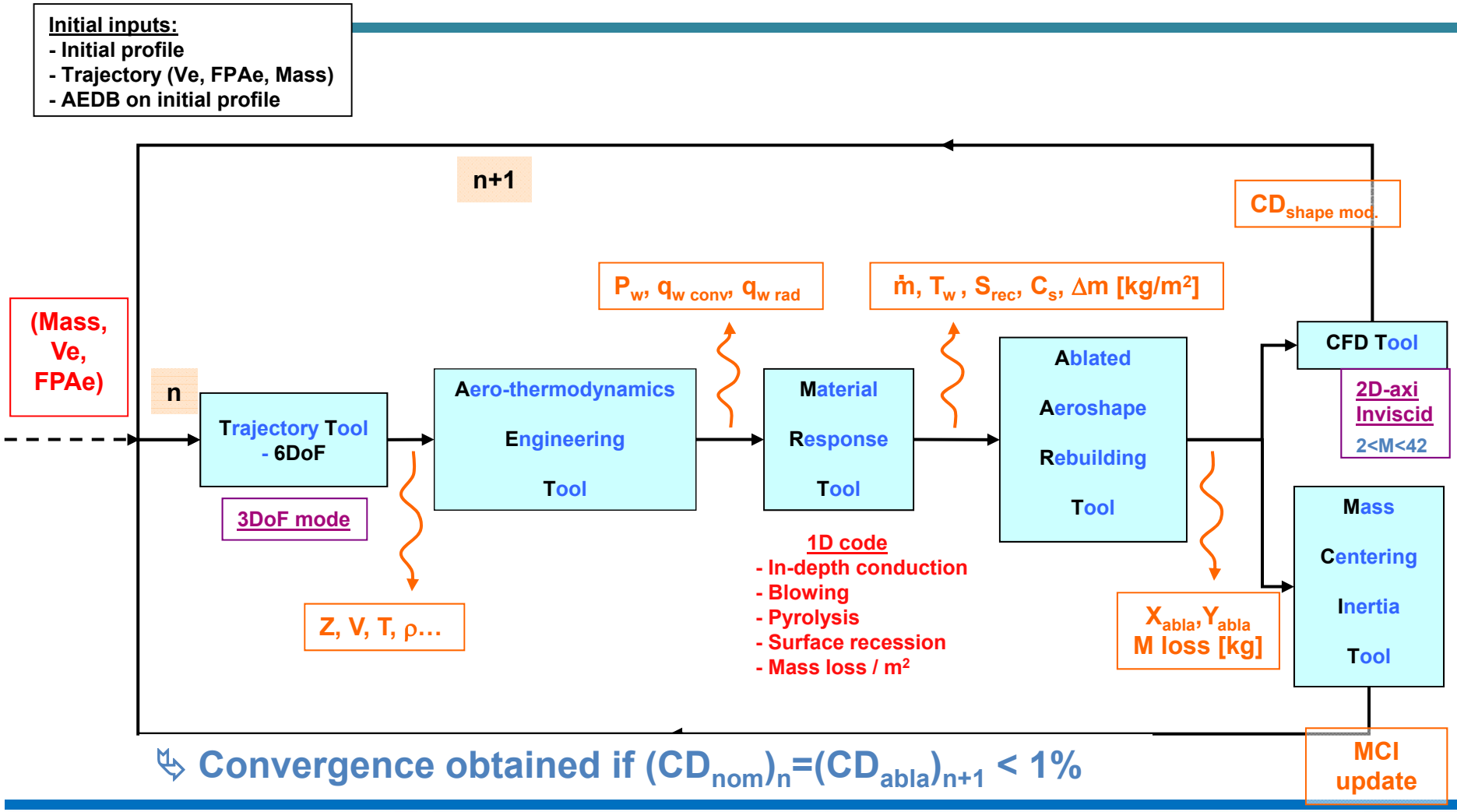
- Modular tool:



↳ **To permit easily the change of module (software) inside a functional class**

- Robustness:
  - ↳ **High requirement of robustness is needed for high speed entry**
- Evolutionary tool:
  - ↳ **Basic requirement for software**
- To perform a complete trajectory within 12 CPU hours
  - ↳ **To keep the Enginneering tool spirit**

WP 4.1 – Tools coupling



↳ **Convergence obtained if $(CD_{nom})_n=(CD_{abla})_{n+1} < 1\%$**

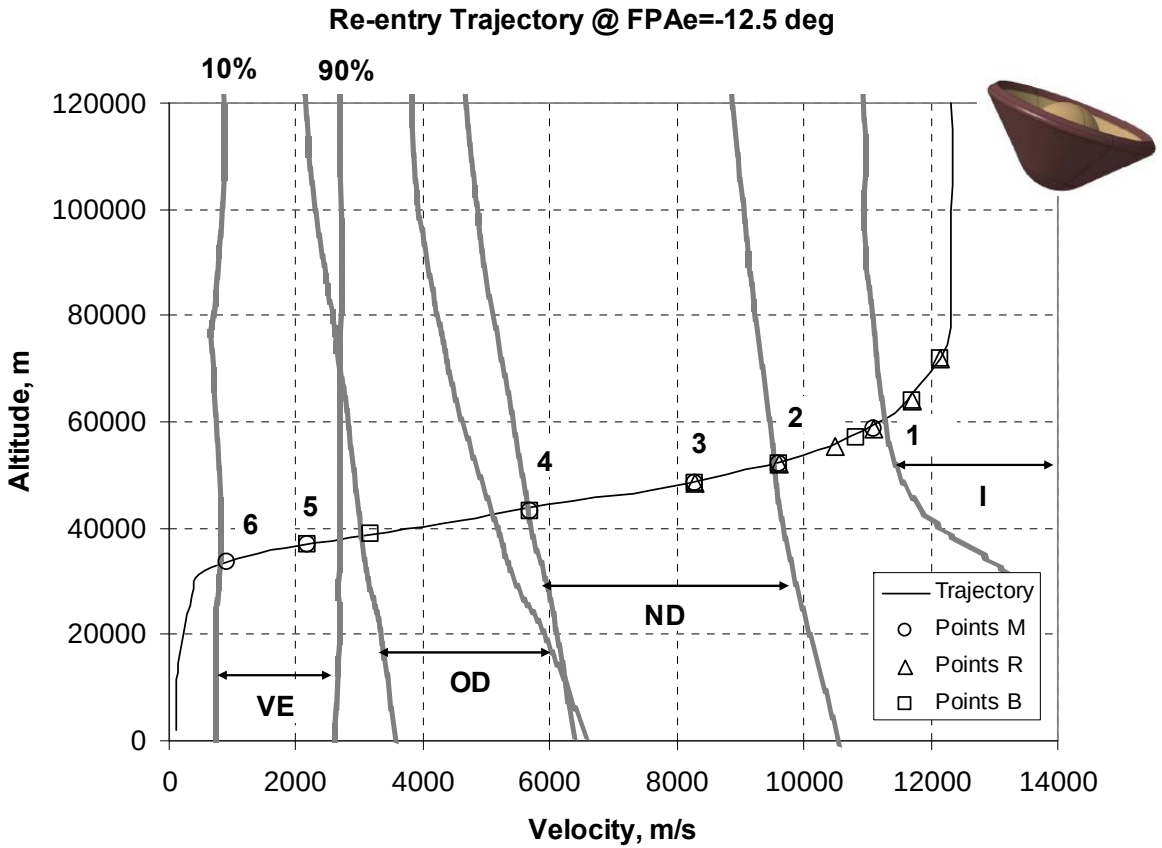
WP 4.2 – Ablation coupling assessment

- Trajectory analysis – Summary

Parameters	Effects compared with nominal case	Maximum levels difference	% vs nominal case	Criticality
Velocity	⇘	50 ⇔ 75m/s	~1 %	Low
Mach	⇘	0.15 ⇔ 0.25	~1 %	Low
Deceleration	⇗	-0.5⇔1g	1 % ⇔ 1.5 %	Low
Dynamic pressure	⇘	0.9⇔1.3kPa	3 % ⇔ 3.5 %	Medium
Stagnation pressure	⇘	2⇔3kPa	2.5 % ⇔ 4 %	Medium
Heat Fluxes	⇘	<100W/m^2	~0 %	Negligible
Heat Load	⇘	1.5⇔2.5MJ/m^2	1 % ⇔ 2 %	Medium
Range	⇘	0.8⇔1.4km	~0.3 %	Low

WP4.3 – Engineering Modelling Correction by CFD

Task # 1: Assessment of aeroshape modification (M)
Task # 2: Assessment of Radiation Coupling (R)
Task # 3: Assessment of Surface Mass Blowing (B)



WP5: Gas-surface interactions modeling

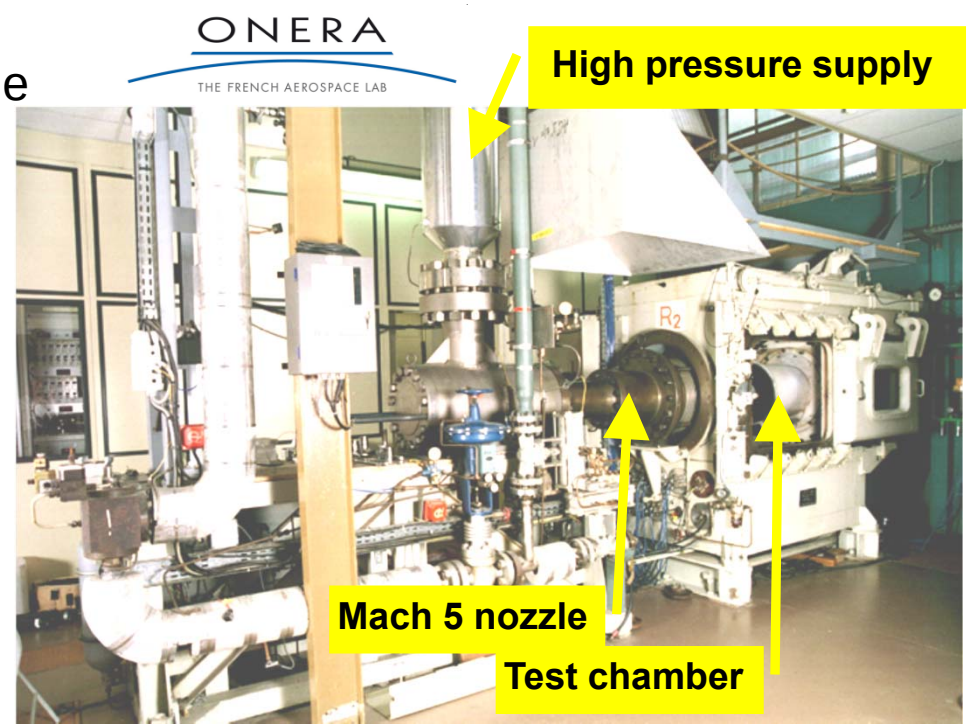
- **WP 5.1 Review of surface roughness**
  - **Bibliography about roughness and blowing (Onera/MSU)**
  - **Turbulence model recommendations (MSU/Onera)**
  - **Critical analysis from real flight (Astrium/MSU)**

- **WP 5.2 Ground experiment**
  - **Tests in Mach 5 blow down wind tunnel (Onera)** → **Next slides**
  - **Test analyses (Euler + boundary layer)**

- **WP 5.3 Model implementation**
  - **Engineering model assessment (MSU/CFS)**

WP5: Gas-surface interactions modeling Experiments in the blow down wind tunnel R2Ch

- **Test Objective** : qualification of the wall heat-flux with roughness effects and different blowing rates (calculated on the maximum heat-flux trajectory [from Astrium study- WP1])
  - without blowing (reference case)
  - with a moderate blowing (m1 = 0.5 m2)
  - with a maximal blowing (m2 to be determined)



- **Wind tunnel characteristics :**
  - Mach 5 nozzle with an
  - exit diameter : 326 mm
  - p_{st} : from 7 10^5 Pa to 50 10^5 Pa ; T_{st} = 650 K
  - Re (L=1 m) = from 5.95 10^6 to 42.5 10^6

WP5: Gas-surface interactions modeling
Experiments in the blow down wind tunnel R2Ch

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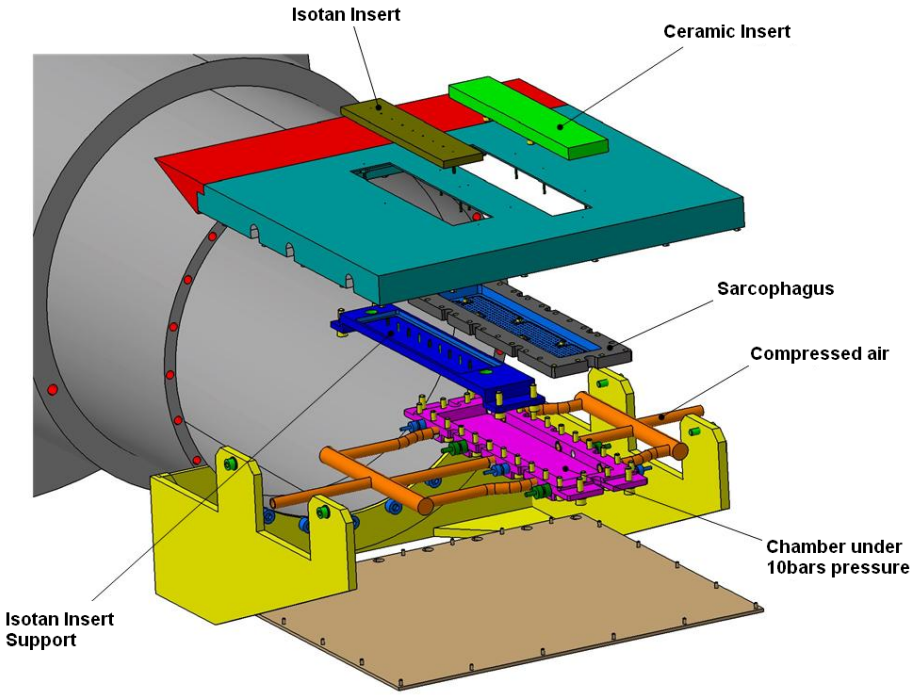
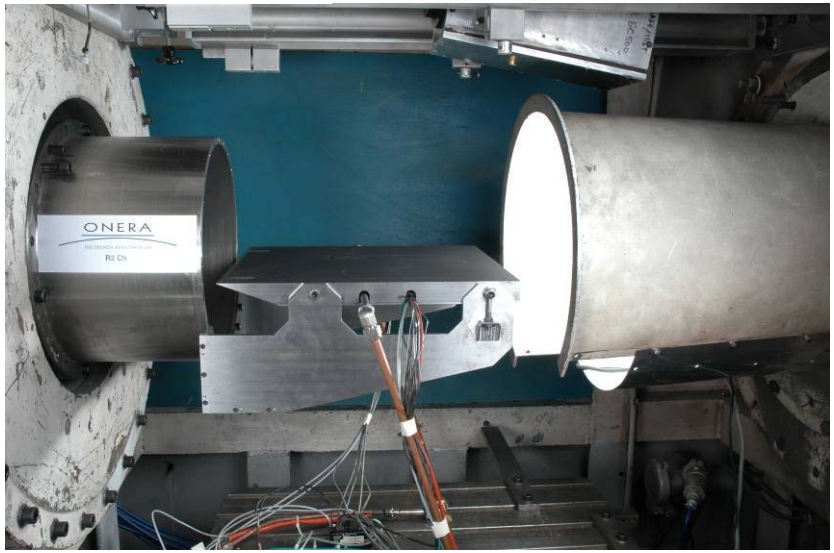
Exploded view of the test set-up





- **Model :** Flat plate with a sharp leading edge, already available from a prior test campaign

During tests :
- Heat flux measurements by infrared thermography,
- Schlieren photographs

WP5: Gas-surface interactions modeling

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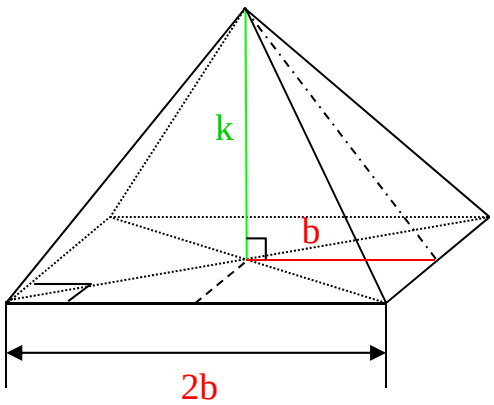
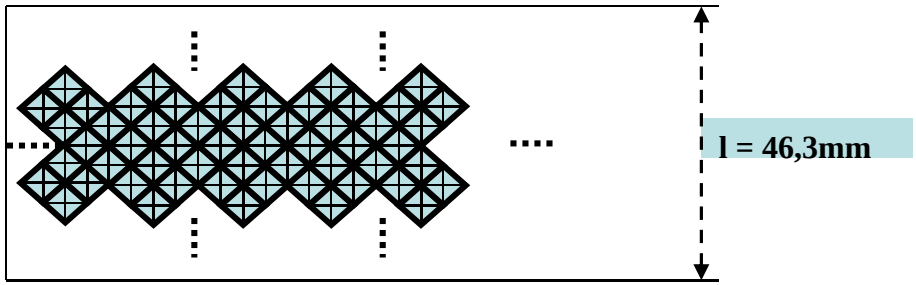
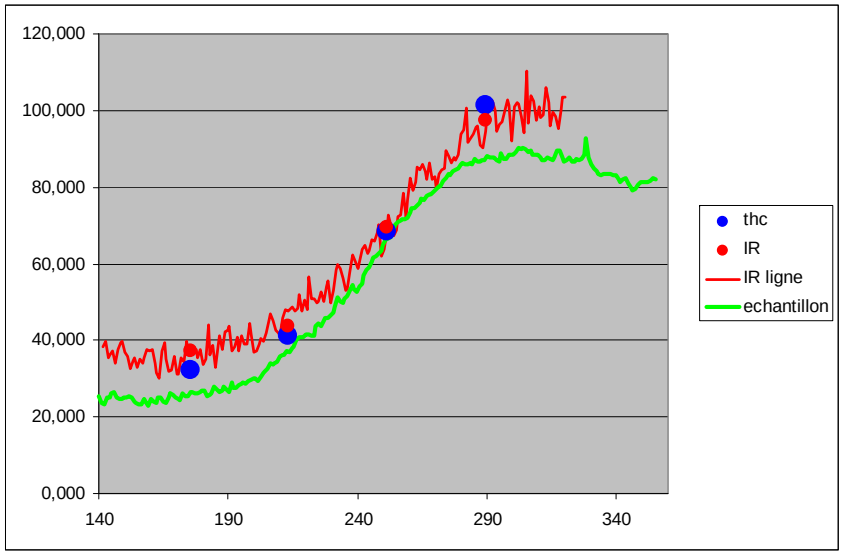


- **Three porous ceramic insert (porosity 48 %)**
  - **without roughness**
  - **with roughness r1 (pyramid height 100 microns)**
  - **with roughness r2 (pyramid height 300 microns)**
- **Characteristics of the roughness : pyramids joined and in staggered rows**



WP5: Gas-surface interactions modeling

Evolution of the Stanton number
St = Φ / ρinf Uinf Cp (Tst – Tw)



(smooth insert without blowing at Pst = 7 105 Pa)

- Available results for first runs (smooth; no blowing)
- Test campaign is being continued
  - blowing effects on smooth insert
  - Rough insert without then with blowing
- Computations and comparison with the experimental results, after implementation of both roughness and blowing effects in different solvers.
  - Euler solver (ONERA)
  - NSMB- Navier-Stokes Multi-Blocks (CFS)
  - Commercial code (MSU)

Next Steps

WP 2	• Review and description of dedicated shock tube and plasma facilities : reports to be posted on website
WP 3	•Performance of arc jet tests in Scirocco •Expertise of tested samples •Manufacturing of technological demonstrator •Synthesis of results on crushable materials
WP 4	•Assessment of coupling effects : synthesis to be updated including last results •Preparation of tests on plasma torch at CNRS
WP 5	•Continuation and completion of ground experiments •Numerical rebuilding

Conclusion

- Rastas Spear is a typical R&D project
  - Part of European Community Framework Programme n°7 (FP7)
- Objective to increase the TRL of
  - Key technologies
  - Methodologies
- Frame of the study has been defined
  - Focus on passive Earth Return Capsule
- Many results have already been acquired
- Remaining steps until end of study will allow completion of overall project objectives
  - Completion Fall 2012…
- Valuable step towards an actual flight mission

Thank you for your attention

More at www.rastas-spear.eu