ESA's Flight Vehicles & Aerothermodynamics Engineering section, activities and an overview of hypersonic projects and technologies

Jeroen VAN DEN EYNDE
European Space Agency

3rd International Symposium on Hypersonic Flight

Air Force Academy (Pozzuoli), Italy, May 30-31, 2019

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Jeroen Van den Eynde *et al.* *(TEC-MPA)*

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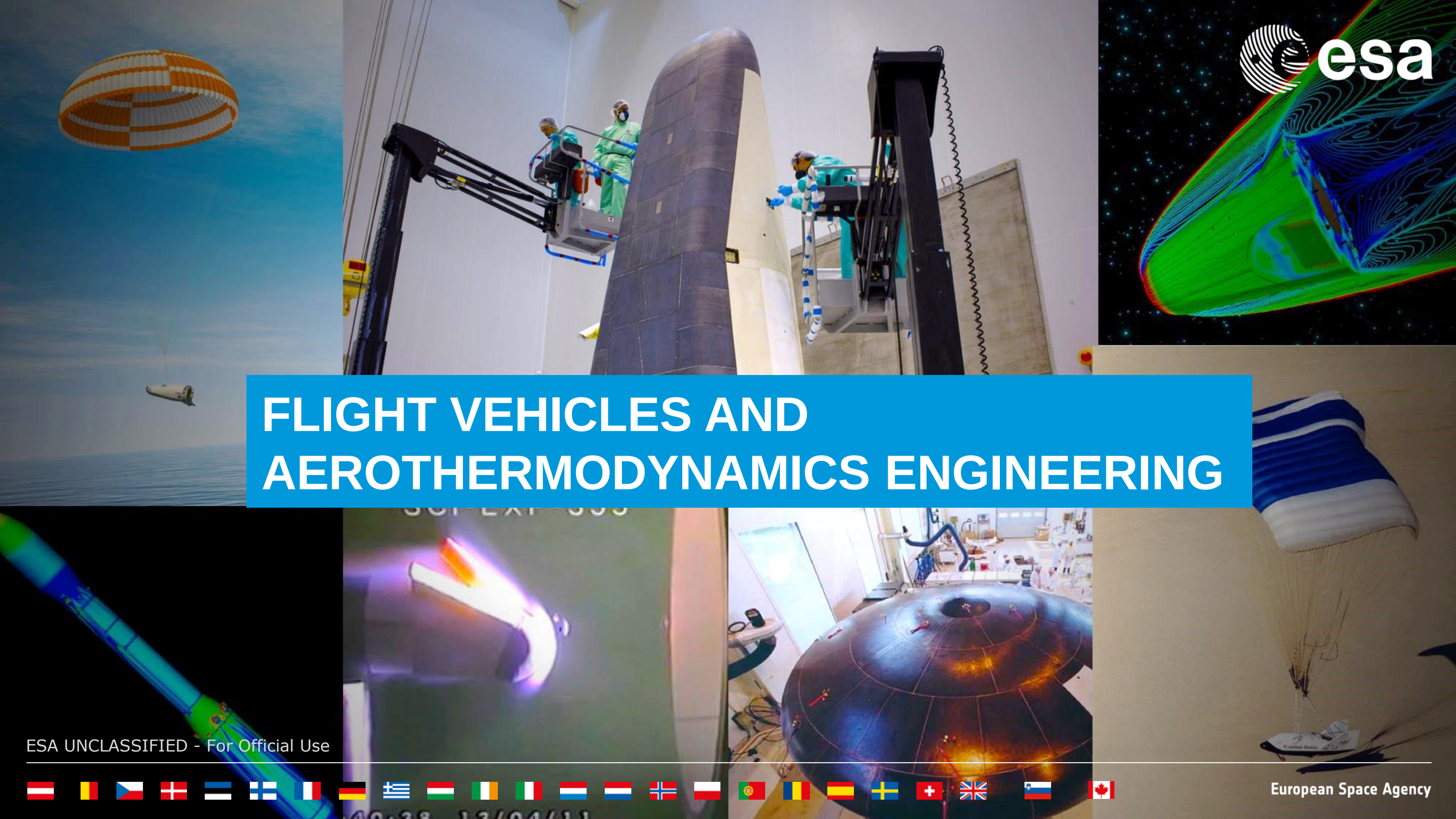
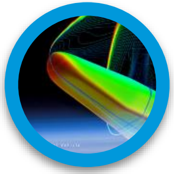


FLIGHT VEHICLES AND AEROTHERMODYNAMICS ENGINEERING

Scope of the section

Focal point for **the architecture design, analysis and technical assessment** of **space transportation vehicles** for suborbital, orbital and exploration applications, including upper stages, (re)-entry, expendable, and reusable vehicles

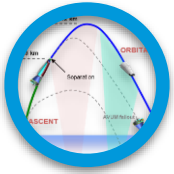


Overall **feasibility and viability assessments**, as well as quick design iterations with the support of the necessary TEC competences

Coordination of the **specialised support and R&D initiatives** with other D/TEC Sections in the frame of the relevant Competence Domains

Engineering support, research, development and testing activities related to flight vehicles, flight physics, aerodynamics, thermodynamics and fluid dynamics engineering and the architecture design and analysis of suborbital, (re-)entry, space transportation, and exploration vehicles

Activities

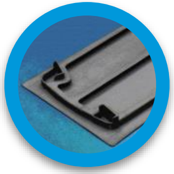


Flight Vehicle Engineering

Upper stages, Re-usability, Micro-launchers, Hypersonic flight

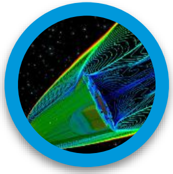
Decelerators

Parachute and parafoil, Inflatable Devices, Drogue Chutes



Design for Demise

Heat transfer and heat rejection, Ablation materials, Heat Shields, Thermal Blankets



Aerodynamics

Shape optimisation, Loads Design, Computational methods, High Speed Atmospheric Flight

Technology Test Beds

Wind Tunnel Testing, Plasma Tunnels, Drop Tests, Avionics Test Beds

Post Flight Analysis

Tool-set for Post Flight Analysis, Exploitation of Flight Data

Thermodynamics

Heat Transfer, Computational Fluid Dynamics and Mechanics

Fluid Dynamics

Lattice Boltzmann Methods, Cryogenic Sloshing, Flows in Micro-gravity

Contamination

Acoustics and Particle Contamination, Plume Contamination

EUROPEAN HYPERSONIC PROJECTS AND TECHNOLOGIES

Hypersonic projects and technologies in Europe

OUTLINE

1. **Entry and Re-entry: exploration and exploitation**
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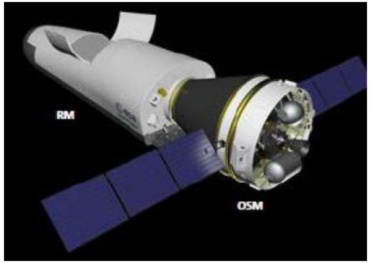
Space Rider Programme

Entry and Re-entry: exploration and exploitation

Goals:

- ➢ To develop an **affordable and sustainable** reusable European space transportation system:
  - to enable **routine access to and return from space**
  - to provide a **standardized platform for Payloads**

  for multiple space application in a multitude of Orbits
- ➢ To focus on the **demonstration of a recurring service**



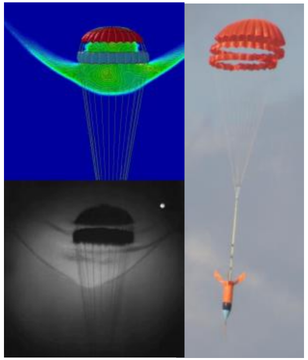
Main Mission Scenario:

- ➢ **Free Flyer:** Microgravity Lab
- ➢ **In Orbit Demonstration:**
  - ▪ Exploration (e.g. robotics)
  - ▪ Earth observation (e.g. instrumentation);
  - ▪ Others (e.g. Earth science, telecommunication).
- ➢ **Surveillance applications** (e.g. earth monitoring, satellite inspection)
- ➢ Phase-B1 completed in December 2017
- ➢ Activities for Phase-B2/C started on January 2018: System PDR in Q4 2018

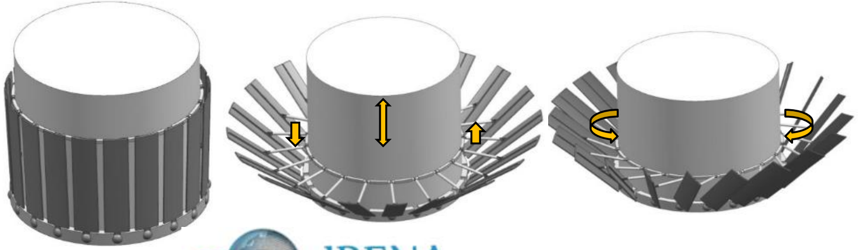
Decelerators: Inflatable vs Deployable

Entry and Re-entry: exploration and exploitation

Decelerator technology (Vorticity/Fluid Gravity Engineering, UK)
Flexible TPS and inflatable / deployable aero-decelerators. Testing in plasma wind tunnel @ DLR-K

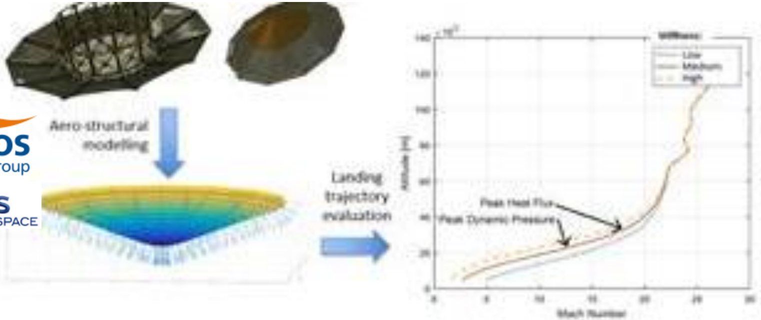


Foldable -Flare for Stabilizing and Control



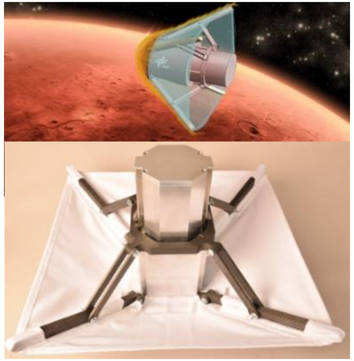
IRENA
International Re-Entry demoNstrator Action

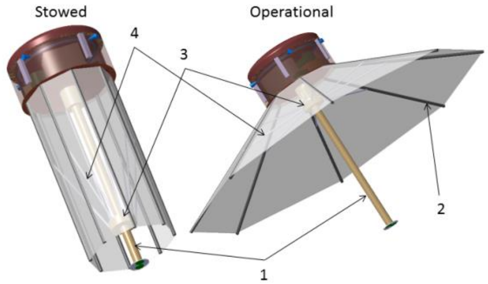
Next-generation Mars entry vehicles, Mars Penetrators, Mars Sample Return….
Modelling of large-diameter deployable entry vehicles. Construction of a 2.5m diameter functional demonstrator model with (low-speed) wind-tunnel deployment tests



deimos elecnor group
AIRBUS DEFENCE & SPACE

Foldable Heat Shield (Exploration)

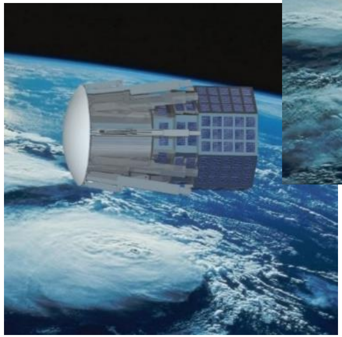


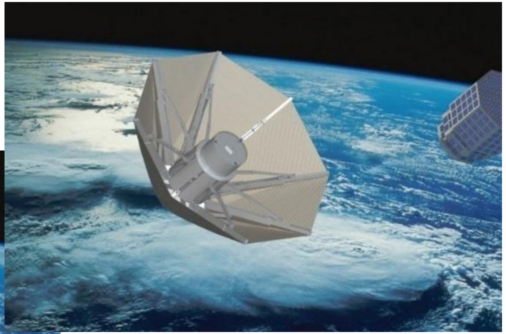


Air Launchable Microsatellite with aerobraking reentry capability MISTRAL

Deployable 20-30kg-class satellite in LEO

- Orbital module (50 W power)
- Umbrella-like reentry system: 15 Kg
- Mission capabilities:
  - Microgravity experiments/ISS
  - Independent LEO experiments
  - Aerodynamic controlled deorbit





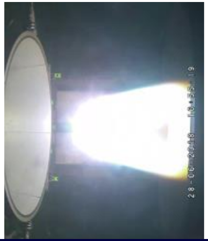
MINI-IRENE FLIGHT EXPERIMENT

MAIN RESULTS ACCOMPLISHED

February 2018
Qualification of the Engineering Model including mechanisms and TPS

April 2018
ESA' Critical Design Review (CDR) successful completed

June 2018
Thermal Qualification of the Flexible TPS at SCIROCCO Plasma Wind Tunnel successfully accomplished



December 2018
Shock & Vibration, Thermal-Vacuum Qualification (Space Qualification Lab) and ESA' Acceptance Review (AR)

NEXT STEPS AND MILESTONES

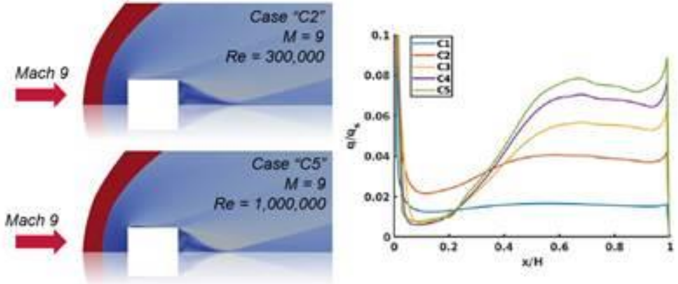
Summer 2019
Launch of the Demonstrator scheduled in 2019 with a Sounding Rocket

Demise: destructive re-entry

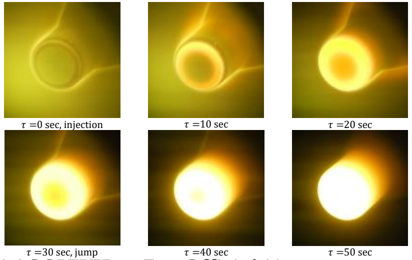
Imperial College London — University of Oxford — esa — CIRA Centro Italiano Ricerche Aerospaziali

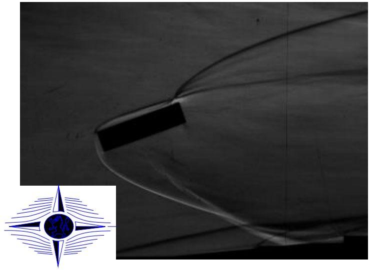
Simulation and experiments for heating rates during demise (Imperial, Oxford & FGE, UK)

Modelling using FGE in-house codes – heating rates to faceted shapes. Heat flux measurements being undertaken in Oxford Low Density Tunnel.



Aerothermodynamic/chemistry testing at VKI





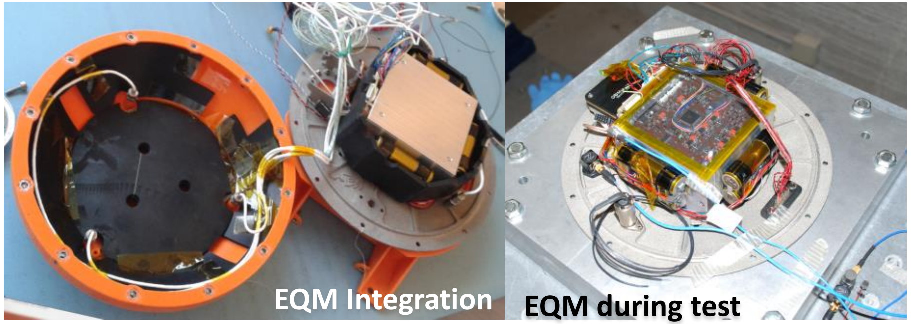
FLPP-3 Demise Observation Capsule DOC

Objective:

- Development of an Observation Capsule, collecting specific data relevant to upper stage break-up and demise, and observing the critical phenomena

Status:

- EQM Qualified w.r.t. mechanical environment at the CIRA Space Qualification laboratories.
- CDR successfully concluded.



Hypersonic projects and technologies in Europe

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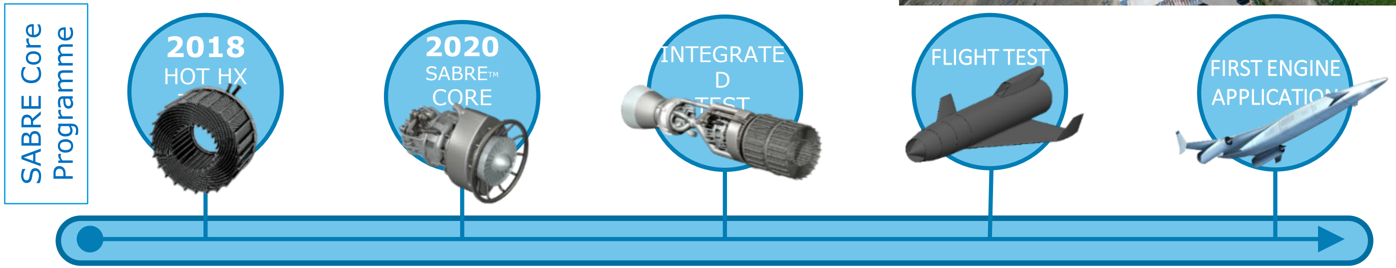
SABRE - SKYLON

Access to Space

Hot heat exchanger test rig completed, testing to commence soon. Inflow air at up to Mach 5 enthalpy

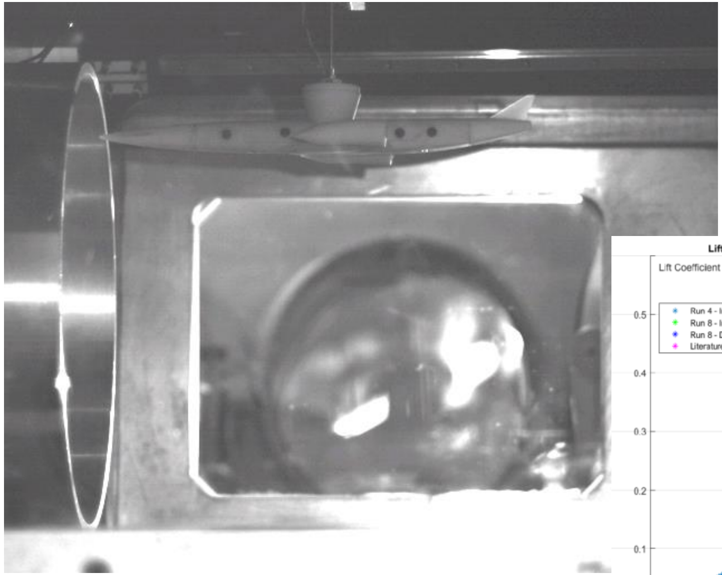
SABRE™ core test demonstrator in PDR review. Test facility ready end of 2019. Testing commences in 2020

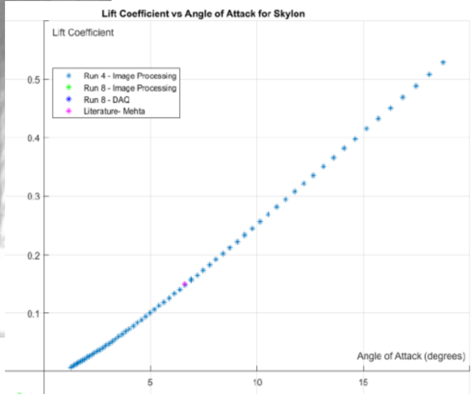


Access to Space by Airbreathing Propulsion

Skylon vehicle aerodynamics (Oxford & Reaction Engines LTD, UK)

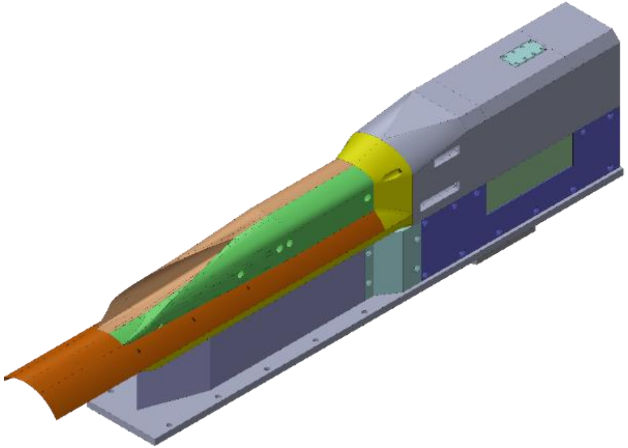
Aerodynamic coefficients measured using free-flight optical measurement technique in Oxford High Density Tunnel





SPARTAN intake testing (Oxford, UK and UQ, Aus)

3 stage to orbit concept – scramjet powered 2nd stage. Developed novel high response mass capture/back pressure device for testing intake performance in Oxford High Density Tunnel



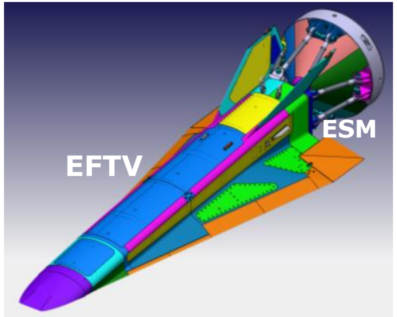
OUTLINE

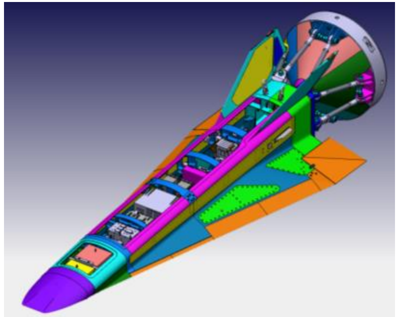
HEXAFLY-INTernational Project co-funded by European Commission, ESA, Russian Federation and Australia

High-Speed Cruisers

Project goals:

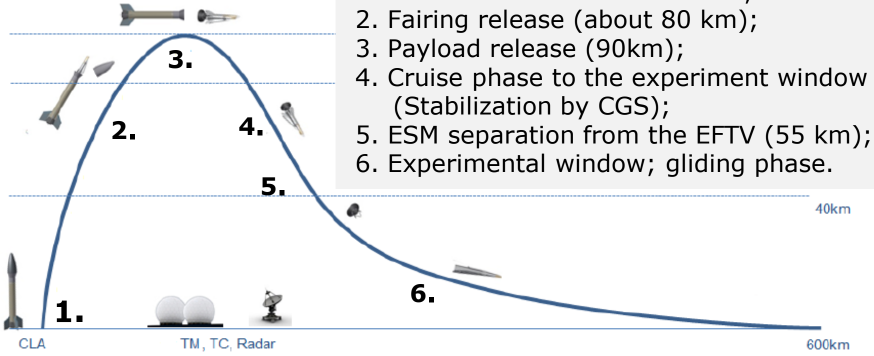
- manufacturing, assembling and flight testing an unpowered hypersonic glider with high aerodynamic efficiency.
- To increase TRL of a number of breakthrough technologies suitable for future high speed civil transportation systems.
- To integrate breakthrough technologies with standard aeronautical technologies.





Mission objective:

- to perform a high-speed flight experiment with a target flight Mach number of 7 to 8 and altitude range between 27 and 33 km.



1. VS-43 Launch Vehicle lifts off;
2. Fairing release (about 80 km);
3. Payload release (90km);
4. Cruise phase to the experiment window (Stabilization by CGS);
5. ESM separation from the EFTV (55 km);
6. Experimental window; gliding phase.

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STRATOFLY

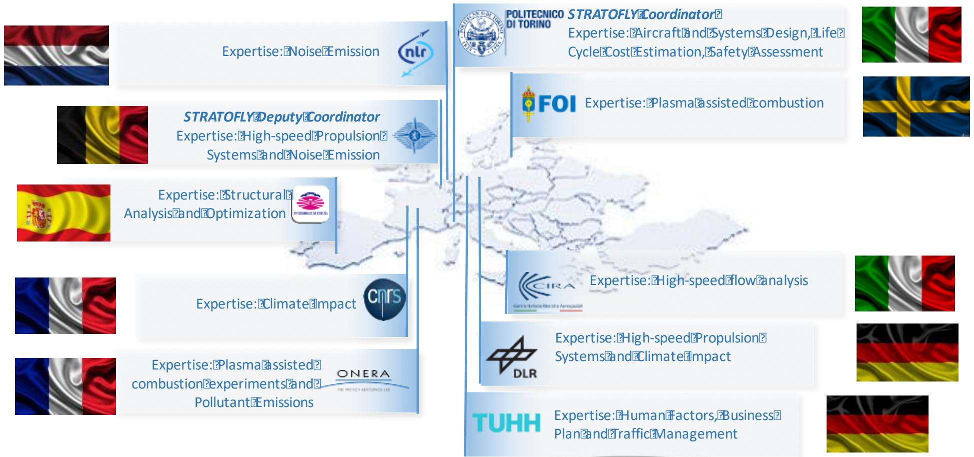
Stratospheric Flying Opportunities for High-Speed Propulsion

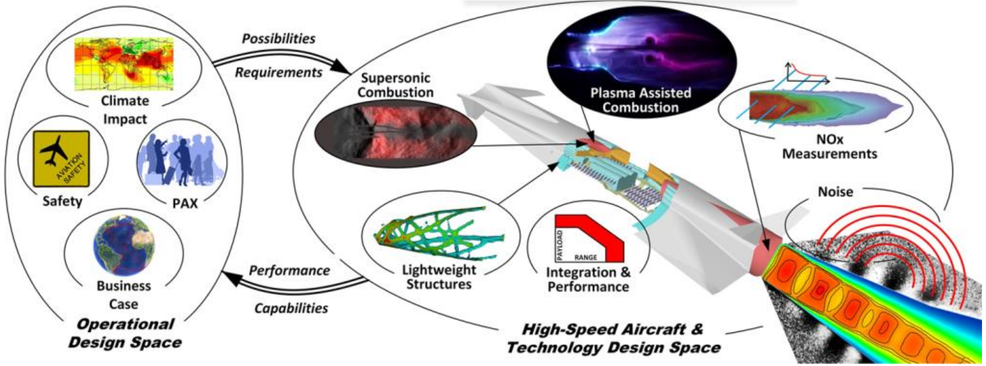
esa

High-Speed Cruisers

STRATOFLY main objectives

- To refine the design and the concept of operations of a Mach 8 reference vehicle.
- To build up on the heritage of the past EU projects to reach the ambitious goal of TRL 6 by 2035 for the vehicle concept.
- STRATOFLY hypersonic vehicle will fly at M8 above 30 km of altitude, performing an antipodal civil passenger transport mission.
- The crucial technologies of STRATOFLY vehicle may represent a step forward to reach the goal of future reusable space transportation systems.





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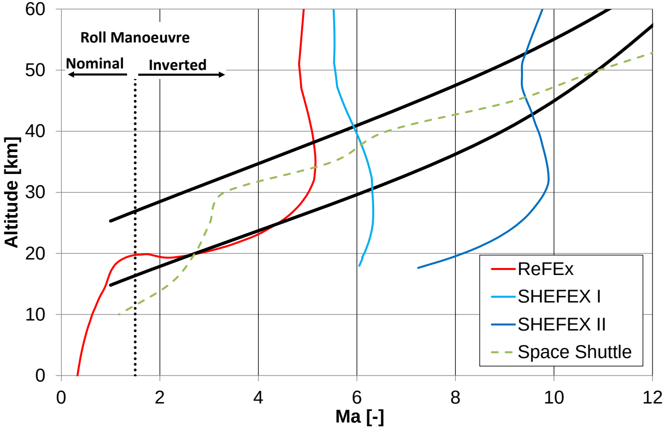
Flight Experiment: Technology Demonstrator

ReFEx – Reusability Flight Experiment



Main goals

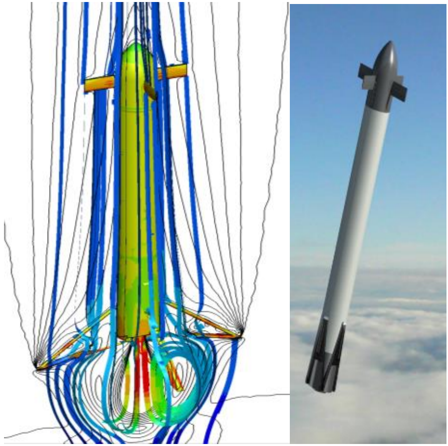
- Technology demonstrator for a winged reusable first stage

LAUNCH PLANNED Q4 2021

CALLISTO: Cooperative Action Leading to Launcher Innovation in Stage Toss-back Operations

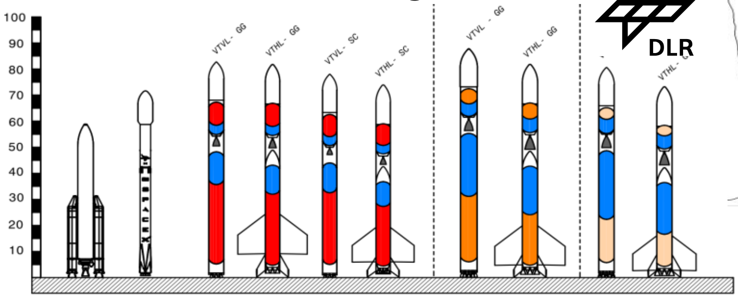
A reusable demonstrator for reusable vertical take-off and vertical landing first stages

- Cooperation between DLR, CNES and JAXA
- 7 flights planned with the same vehicle starting from 2021
- Demonstrate key technologies required for an operational VTVL RLV



DLR ENTRAIN System Study

investigation of different launchers with reusable first stage



Reusability for Launch Vehicles

Flight Experiment: Technology Demonstrator

Flight testing of innovative RLV-return mode "in-air-capturing" in AKIRA and FALCon projects

- **Running 2017 – 2019, Mid-Term Review finished in November 2018**
  - Systematic investigation of RLV return modes & flight demonstration of "in-air-capturing" at lab-scale (H2020: **FALCon**!)
  - Test of reusable cryogenic tank insulations in integrated object with HM and external TPS-concepts
  - Advanced RLV-structure concepts, "thin-ply"-CFRP-material
  - Increasing lifetime & # cycles of rocket thrust chambers by TMF-tests

FALCon

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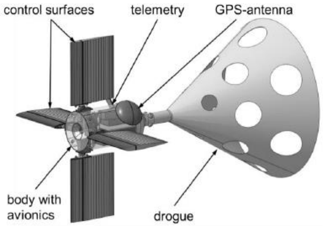

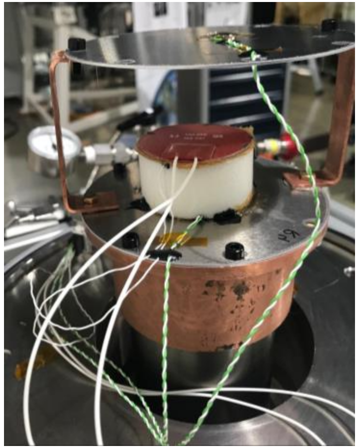

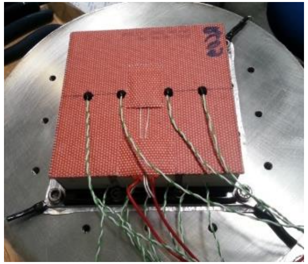

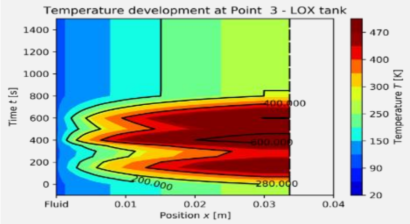

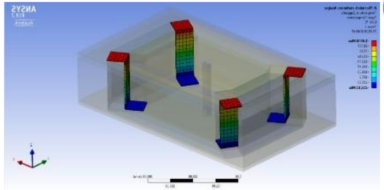

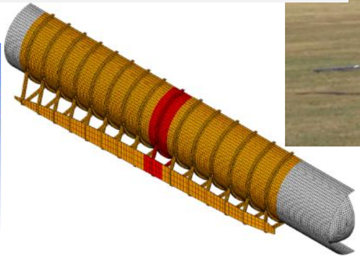

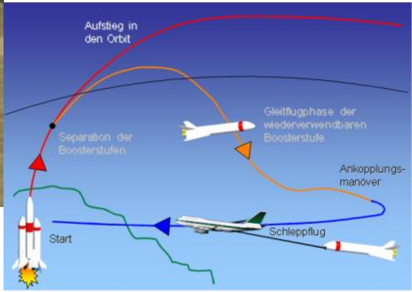

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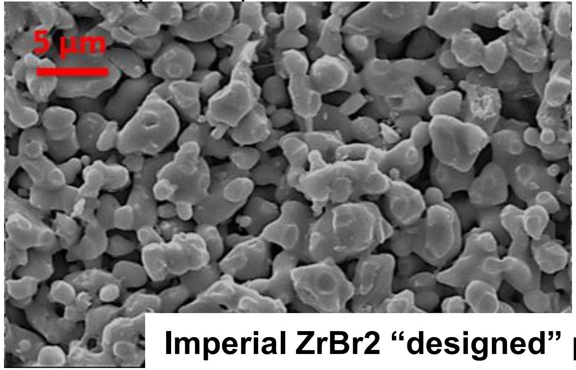
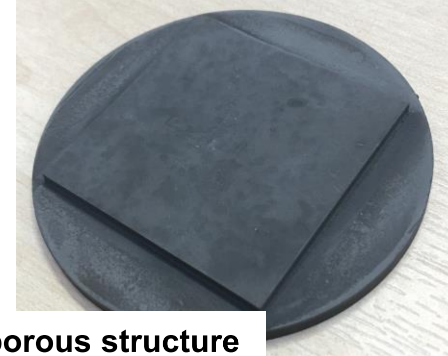
Transpiration Cooling

University of Stuttgart

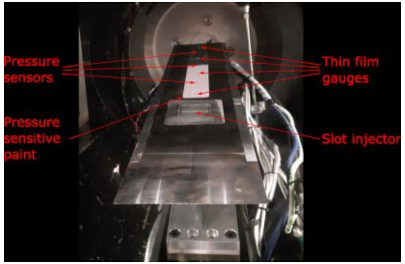
- 5 year programme, focussed on development of fundamental understanding and design methodology
- Multi-institutional, cross sectorial & spans research from material development, heat transfer and simulations

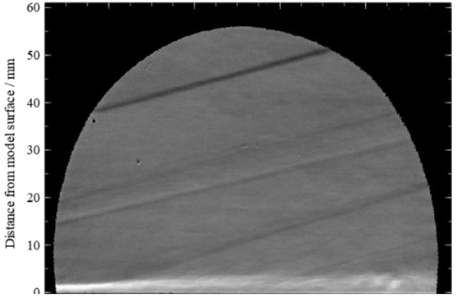
Hypersonic Technologies RTD



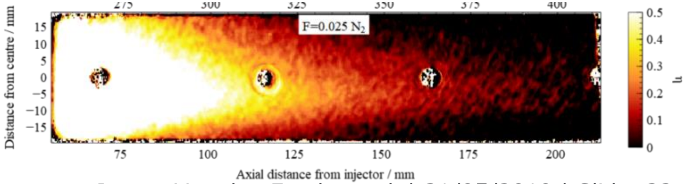


Imperial ZrBr2 “designed” porous structure





Mixing testing on a flat plate, Oxford HDT



Oxidation protection testing, IRS PWK4

IRS PWK4
Air, 3 kPa, ~6 MW/m²

Virgin | N_2 trans cooled 70 → 30 mg/s | He trans cooled 2.5 → 1 mg/s | Uncooled

Next Generation Ceramic Composites For Combustion Harsh Environments And Space

C3HARME

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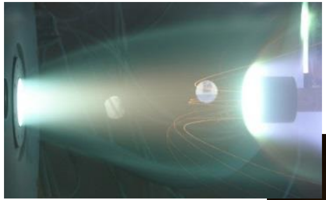
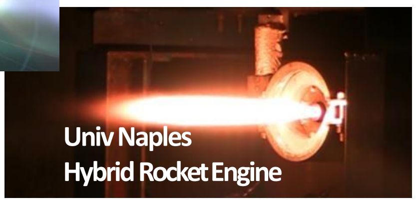
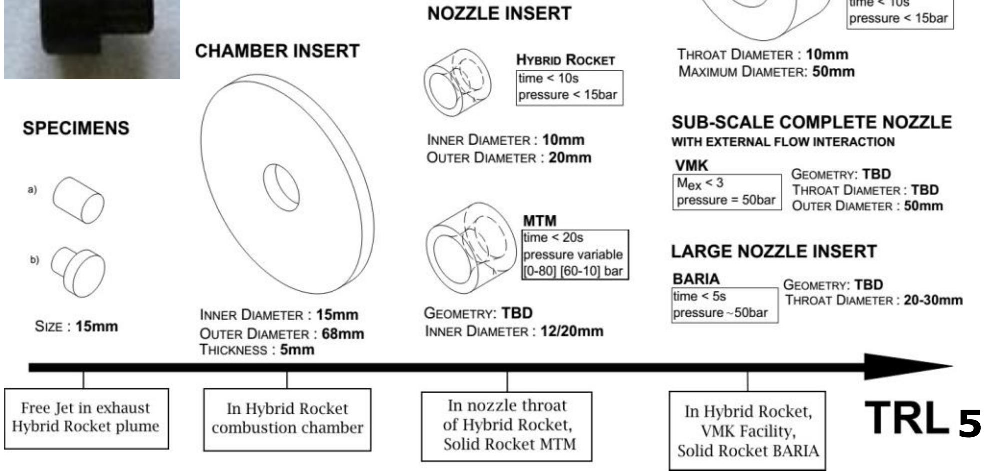
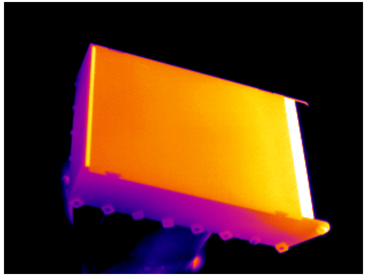
Hypersonic Technologies RTD

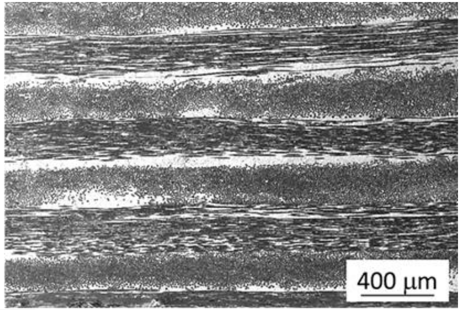


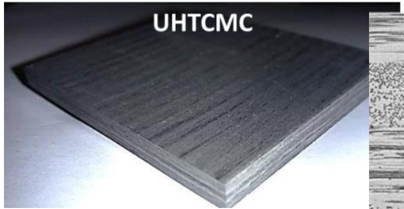


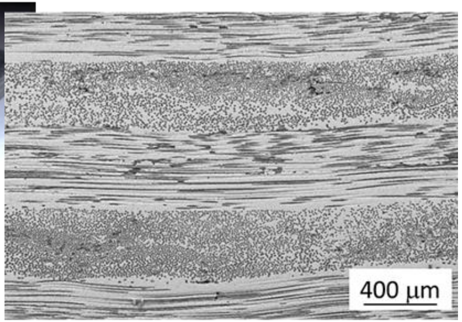


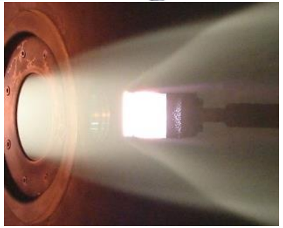
TRL 5/6











National Research Council of Italy
istec Institute of Science and Technology for Ceramics

Hypersonic projects and technologies in Europe

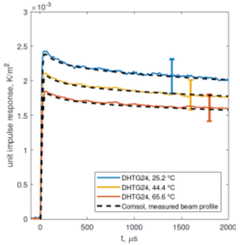
OUTLINE

1. Entry and Re-entry: exploration and exploitation
2. Access-to-Space: Airbreathing and/or Rocket Mode
3. High-Speed Cruisers
4. Flight-Experiment: Technology Demonstrator
5. Hypersonic Technologies RTD
6. **Facilities and Measurement Techniques**
7. Hypersonic Fundamentals

National Wind Tunnel Facilities - UK

Diamond based heat flux gauge (Oxford, UK)

Fast response (10 µs), high temperature rise and UV pulsed laser based calibration. Extremely robust to survive particle impact in shock / expansion tunnels.

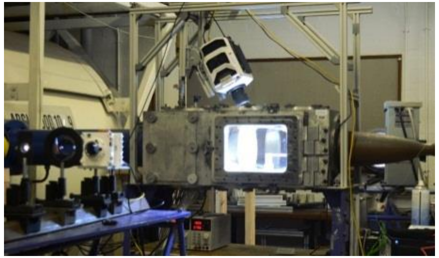


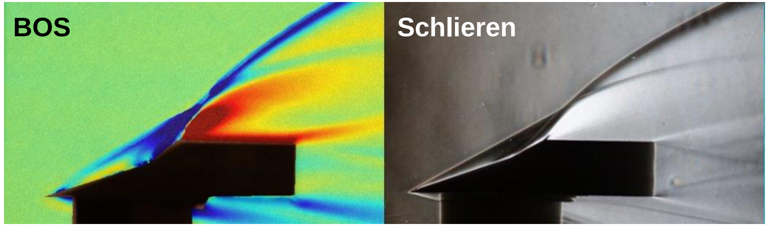
Heat flux gauge (left) and Impulse response (right)

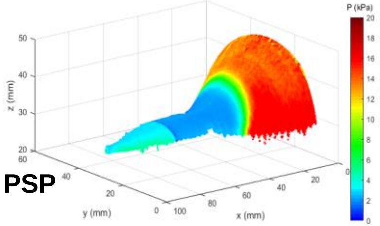
Optical Diagnostics (Machester, UK)

Several techniques in development in lowdown tunnel (HSST)

University of Manchester



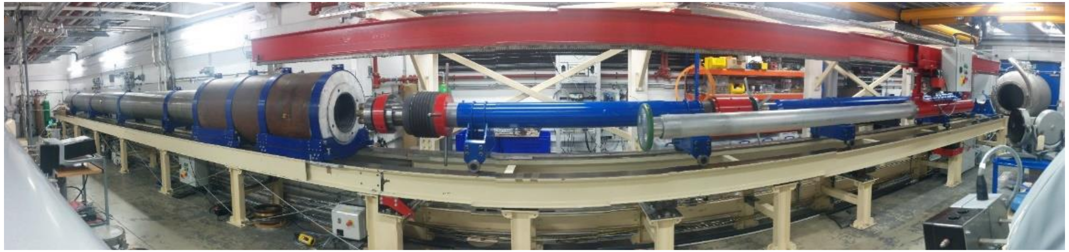




Light Field PSP

T6 Stalker tunnel operational (Oxford, UK)

Free-piston commissioned to 60 MPa and compression ratio of 60. Currently operating in expansion tube mode (10 km/s) & shock tube mode

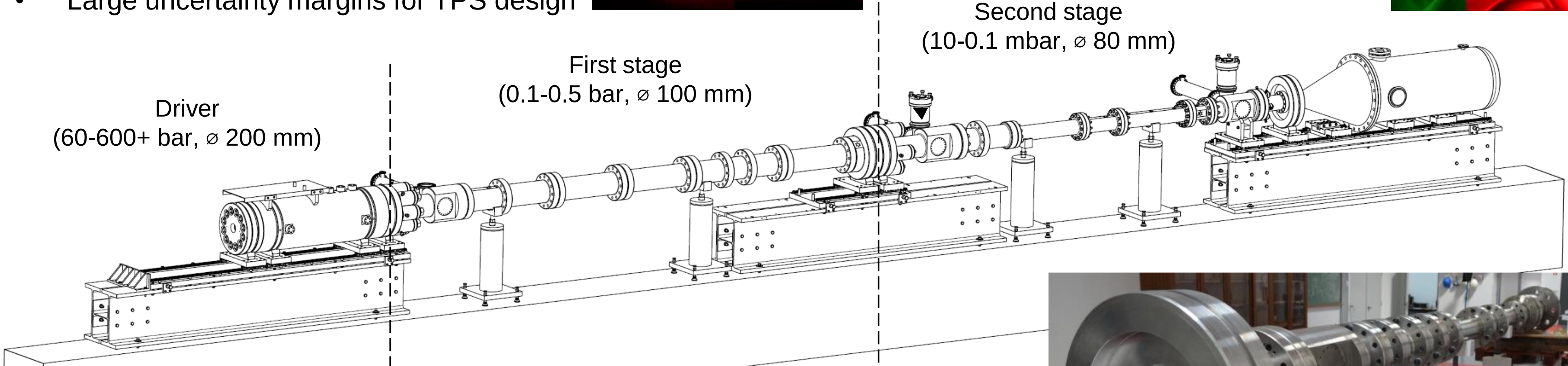


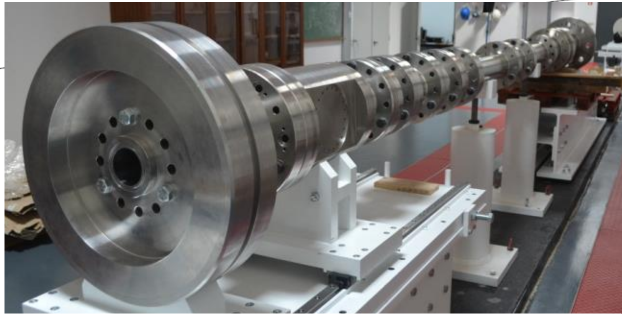
T6 Stalker Tunnel

European Shock-Tube for High Enthalpy Research (ESTHER)

(Re-)Entry of Planetary Probes

- Radiative heating dominates
- Non-equilibrium thermo-chemistry
- Large uncertainty margins for TPS design





ESTHER: Two-Stage combustion-driven ($He/H_2/O_2$ mixture) to reproduce thermo-chemical physics relevant to Earth entry (N_2/O_2), Mars & Venus entries (CO_2/N_2), Titan (CH_4/N_2): 5 to 15 km/s; Gas Giants: Uranus, Neptune & Saturn (H_2/He): 11 to 18 km/s

Status: ESTHER Inauguration on 24 July '19
Qualification & Operational Tests afterwards.

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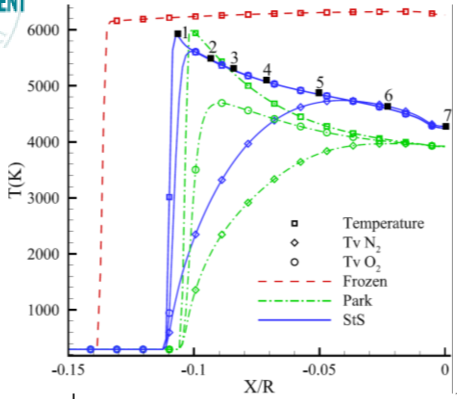
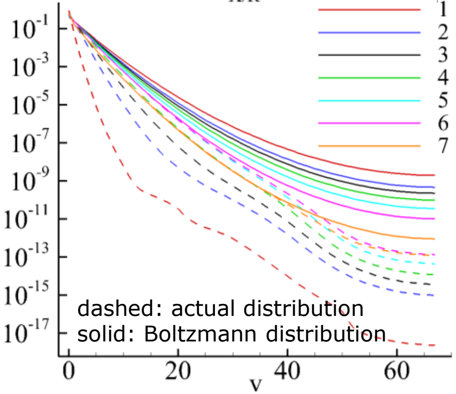
CNR NANOTEC INSTITUTE OF NANOTECHNOLOGY
DEPARTMENT OF MECHANICS MATHEMATICS & MANAGEMENT

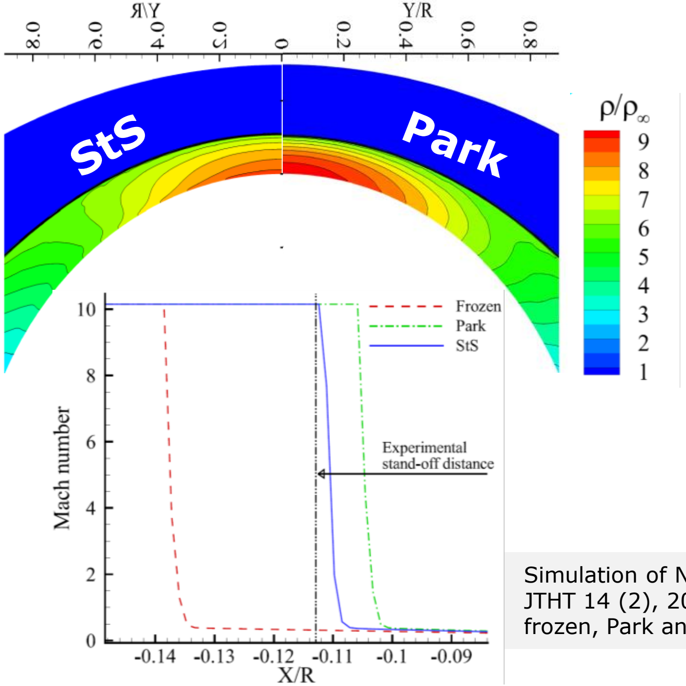
Hypersonic Air Flow with State-to-State Vibrational Kinetics on GPU's

Hypersonic Fundamentals

- State-to-state (StS) vibrational kinetics of air implemented in a Navier-Stokes 2D CFD code, adapted to run on Multi Graphical Processing Units (GPU) using MPI-CUDA







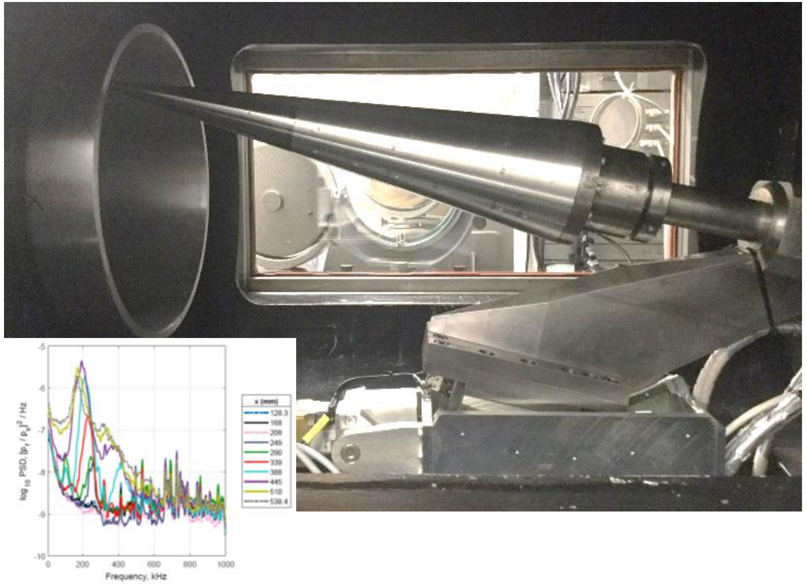
Simulation of Nonaka test (Nonaka et al., JTHT 14 (2), 2000) and comparison among frozen, Park and StS kinetics results

Hypersonic Fundamentals

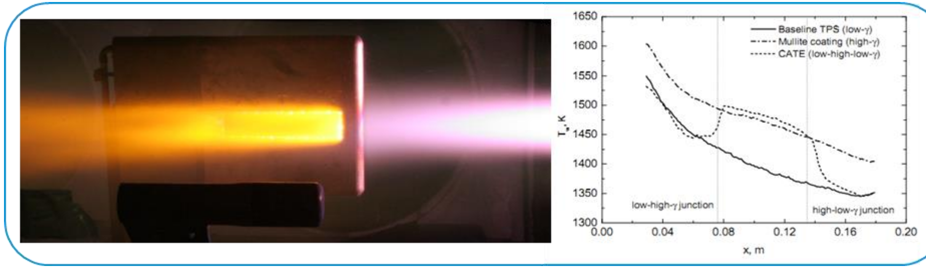
Hypersonic BL transition

UOXF, VKI, DLR, UNBW…

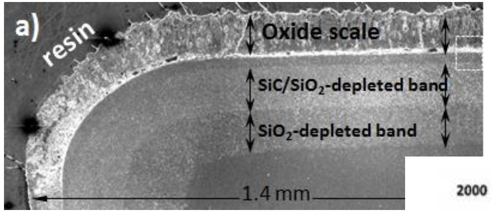
Measurements of mixed instability waves (1st, 2nd and cross-flow) investigating effect of wall to total temperature



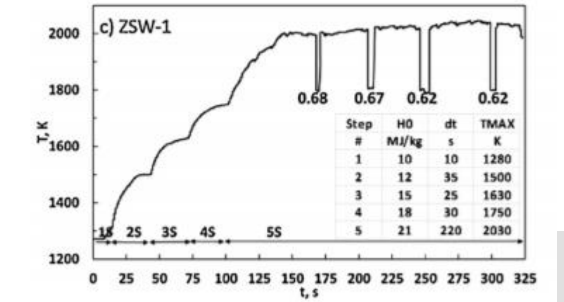
Reentry Gas/Surface interaction phenomena duplicated in Plasma Wind Tunnel facility



Effect of surface materials properties



Temperature and emissivity evaluated



CONFERENCES & WORKSHOPS

FAR 2019 Conference – Monopoli, Italy

- International Conference on **Flight vehicles, Aerothermodynamics and Re-entry missions and engineering (FAR)**
- September 30th - October 3rd, 2019
- Outcome of the successful series of Symposia on Aerothermodynamics for Space Vehicles, the Workshops on Thermal Protection Systems and other international events organised by ESA in the last few years in the field of (Re)-entry and new Vehicles design and engineering.
- Abstract submission already closed.
- https://atpi.eventsair.com/QuickEventWebsitePortal/far2019/website

HiSST 2020 Conference – Bruges, Belgium

- 2nd International Conference on
  High-Speed Vehicle Science and Technology
- 20-24 April 2020
- Conference topics cover High-Speed Missions and Vehicles, Propulsion Systems and Components, Thermal, Energy and Management Systems, Guidance & Control Systems, Materials and Structures, High-Speed Aerodynamics and Aerothermodynamics, Testing & Evaluation, Operation and Environment, Hypersonic Fundamentals and History
- Abstract submission deadline:
  30 September 2019
- https://atpi.eventsair.com/QuickEventWebsitePortal/hisst-2020/website

ESA's Flight Vehicles & Aerothermodynamics Engineering section, activities and an overview of hypersonic projects and technologies

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