CALLISTO: a Demonstrator for Reusable Launcher Key Technologies

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DLR, JAXA and CNES

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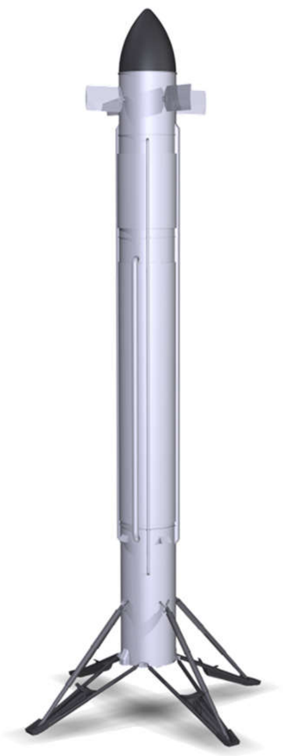
Reusable vertical take-off and vertical landing demonstrator

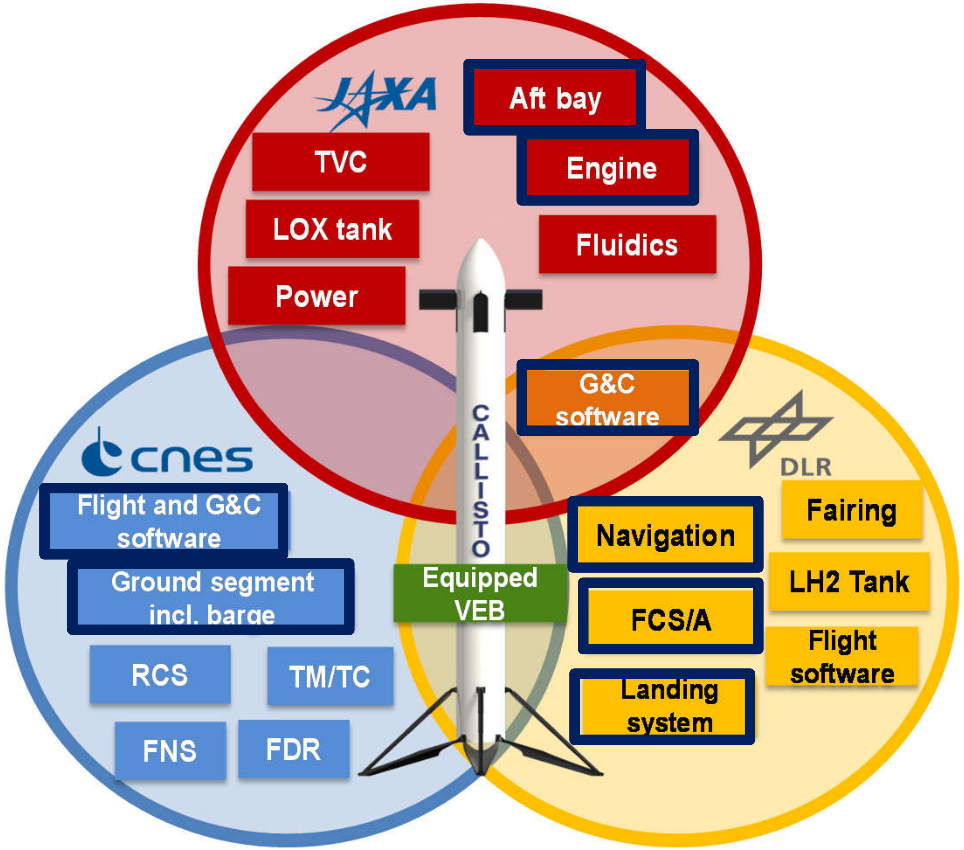


- Cooperative Action Leading to Launcher Innovation in Stage Toss - back Operations
- Official start in June 2017 during Paris airshow
- Collaboration of three partners (JAXA, CNES and DLR) following the same goals:
  - reducing the cost of access to space
  - increasing the operational flexibility of launch vehicles
- And translated in a root need to be fulfilled by 2022:

  Improve knowledge of and demonstrate key features (technical, economics) for developing and operating a reusable VTVL first stage.

The vehicle: 13.5 m high, 1.1 m diameter, less than 4 tons at lift-off
(for more details see 2019-g-02)

Subsystem overview



- Fair sharing of the tasks considering the experience and know-how of each partner

- Numerous technologies and aspects (including system architecture, aerodynamics, MRO) specific for reusable vehicles

- Other subsystems designed for several reuses (10 flights but many more cycles)

The demonstration of these technologies and aspects on CALLISTO will help:

- reducing risks for developing future RLV
- optimising the design

FCS/A aerodynamic flight control system
FDR: flight data recorder
FNS: flight neutralization system
G&C: guidance & control
RCS: reaction control system
TVC: thrust vector control
TM/TC: telecommand and telemeasure
VEB: vehicle equipment bay

Guidance and Control

Tasks: Achieve **pin-point landing accuracy** despite uncertain flight conditions, i.e.

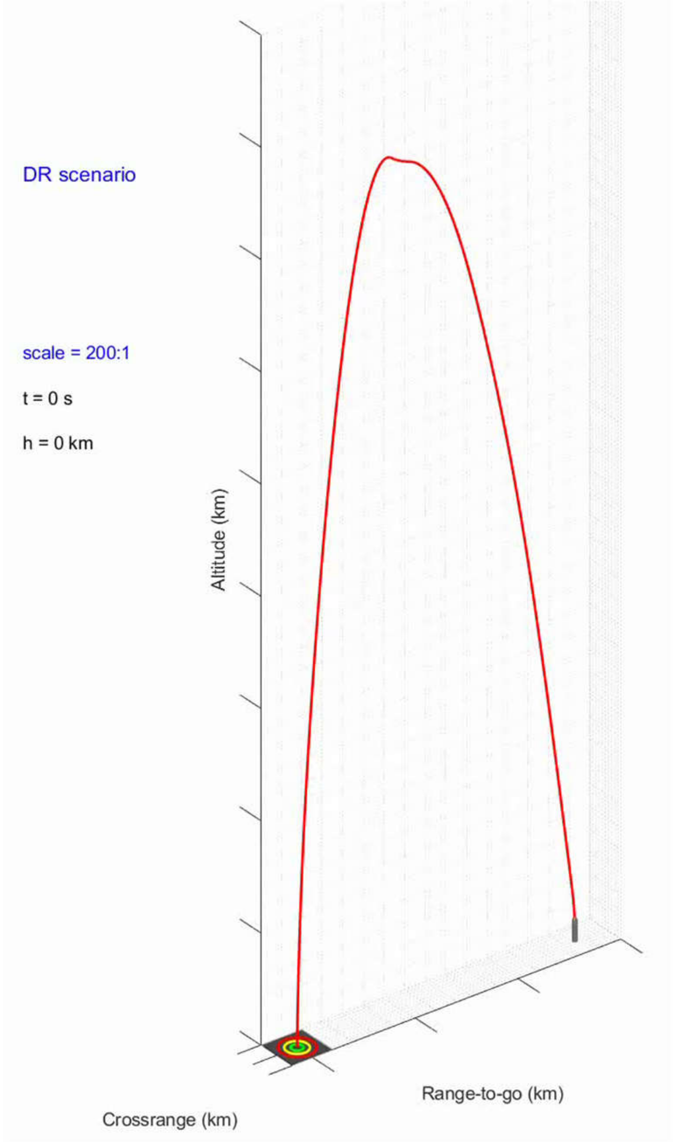
- Environmental conditions (i.e. wind, atmospheric density)
- Uncertainties in vehicle parameters (i.e. aerodynamics, mass properties)
- Propellant sloshing

Challenges:

- **Feedback control alone shows its limits** to achieve required performance
- Trajectory prediction and **autonomous trajectory (re-)planning required** during flight

Solution Approach:

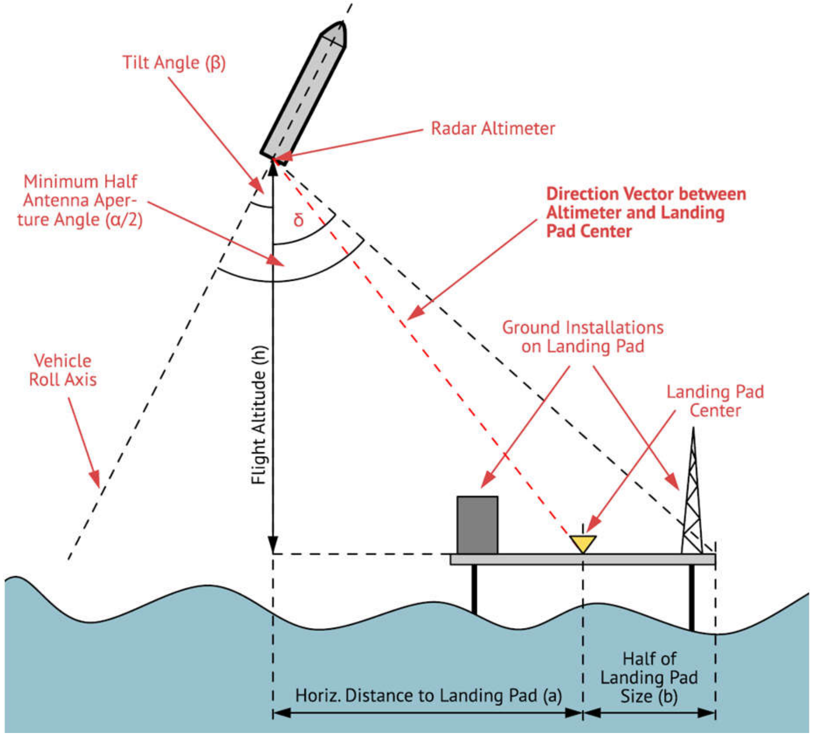
- Predictive and reactive capability through closed-loop guidance based on **convex optimization**
- Guaranteed robust tracking performance through **structured H_∞ design**



Hybrid Navigation System (HNS)

Tasks:
Provide a **navigation solution** and a **time reference** for the whole vehicle, but especially for flight guidance and control purposes.

- Position, Velocity, Attitude, Attitude Rate
- Air Density, Mach Number, Angle of Attack/Sideslip
- Date and Time



Challenges:

- Very high performance requirements which **cannot be fulfilled using conventional navigation systems**
- Operation of sensors in **proximity to an operating rocket engine** (sensor ↔ plume interference, vibration)
- **Moving landing pad** on a floating barge in the open sea

Solution Approach:

- DGNSS, radar altimeter, fusion of signals

On-Board Software and OBC

Tasks:

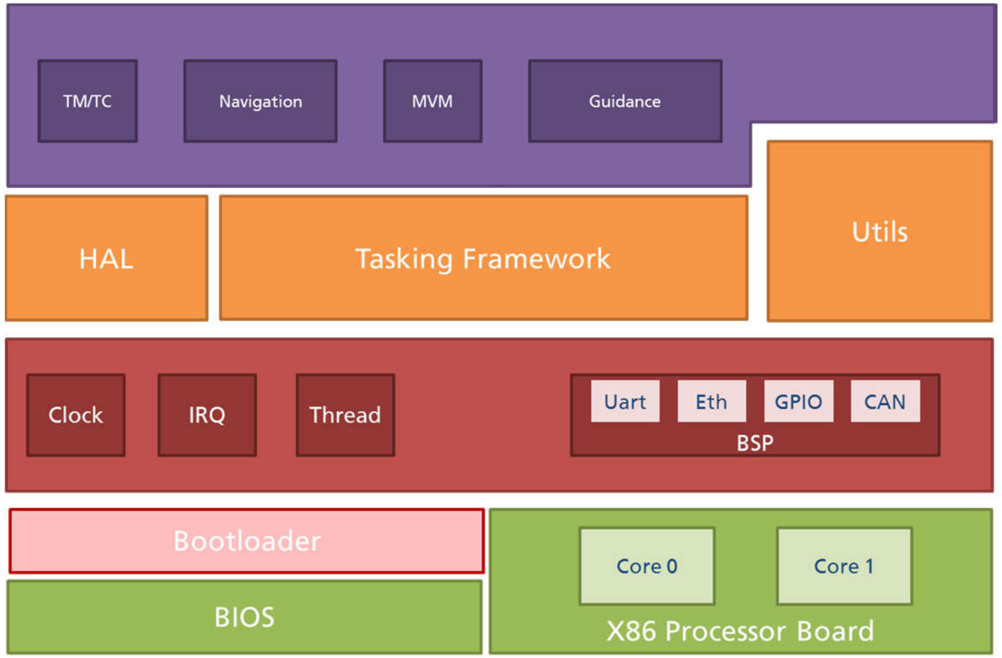
- **Optimize in real time** the trajectory
- Manage the vehicle
- Accommodate the key design decisions of the avionics system

Challenges:

- Real-Time Computation on several cores
- Support for **distributed subsystem**

Solution Approach:

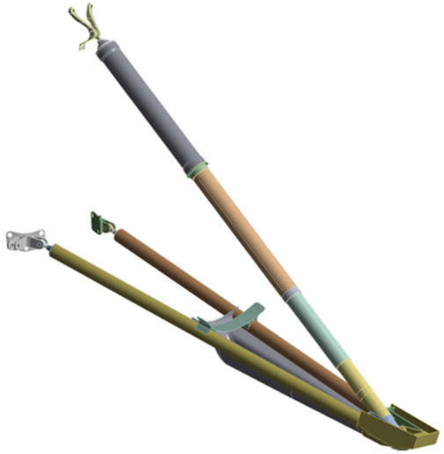
- Multicore real time computing based on RTEMS and with support of Symmetric Multiprocessing (SMP)
- Test-Driven Development

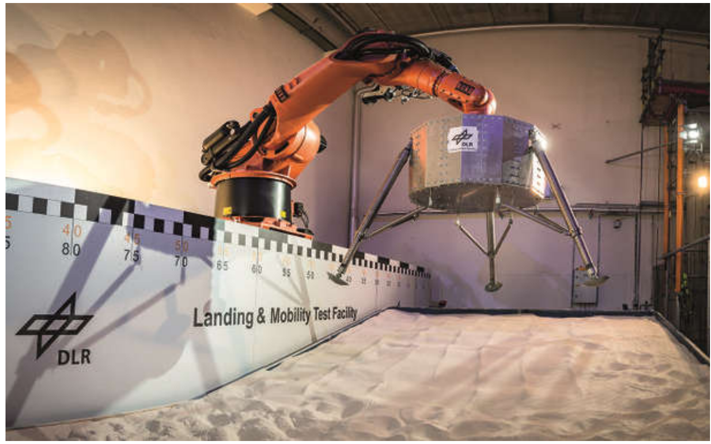


Landing dynamic and approach and landing system design

Tasks:

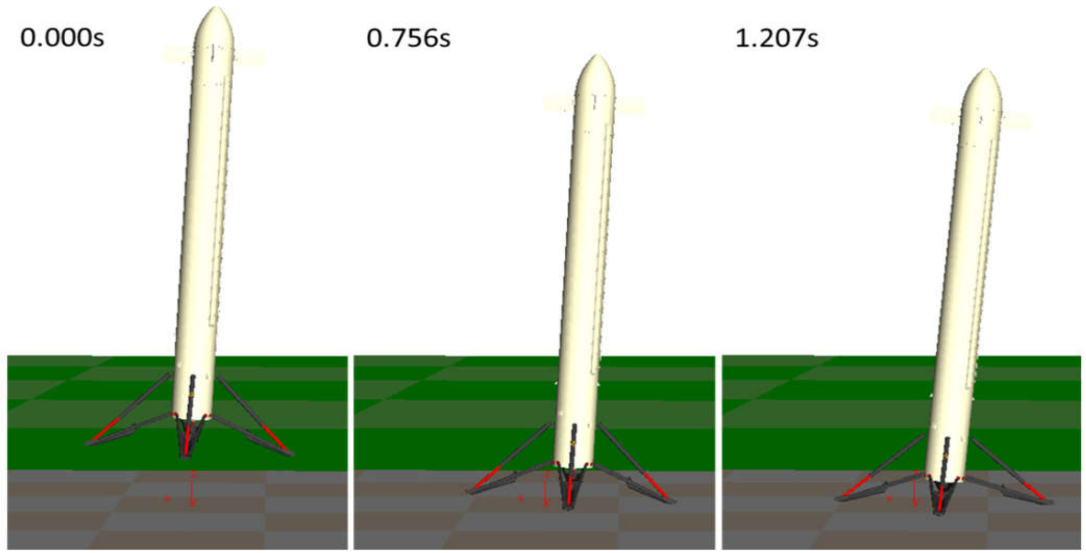
- Absorb remaining kinetic energy
- **Limit the loads** to other structures
- Keep the vehicle in **stable conditions** also after landing





Challenges:

- Large **flight domain**
  - Approach velocity
  - Approach attitude
  - Weather conditions (gusts)
- Very high success rate

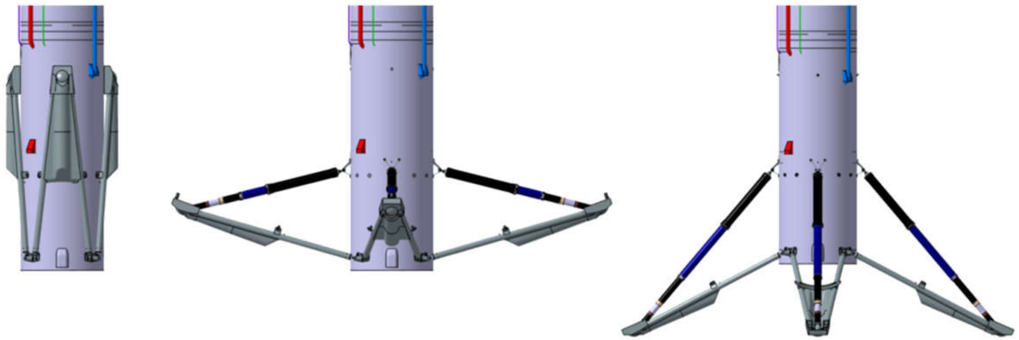


Solution approach:

- Computer modelled landing dynamic applied to **Monte Carlo simulations**
- Several **test campaigns** to validate the design

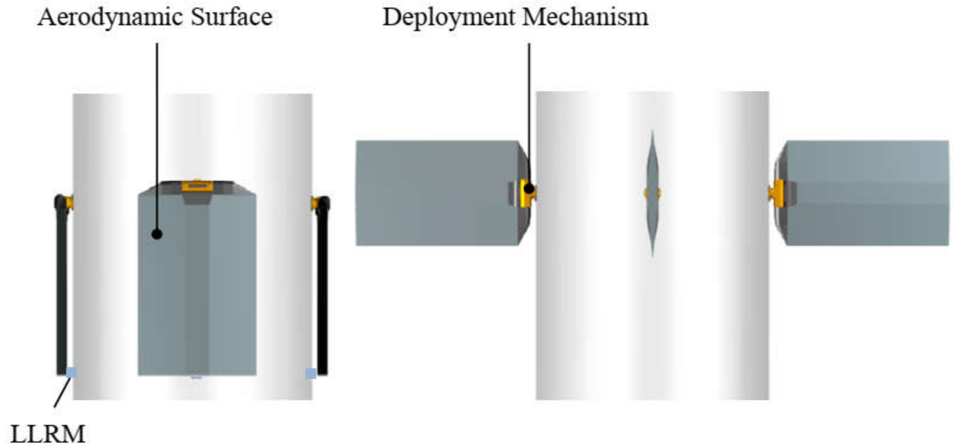
DLR JAXA cnes

Deployable structures



Tasks:

- Adapt the vehicle to the **different flight phases**:
  - For aerodynamically controlled phase
  - For the landing
- Be able to be stowed easily to prepare for next flight



Challenges:

- **Lightweight**
- High thermal loads
- High aerodynamic loads
- Short time window to perform the **deployment**

Solution approach:

- 4 pneumatically **deployable landing legs**
- 4 **deployable aerodynamic control surfaces**
- Several test campaign to validate the design

Aerodynamics (1/2)

Tasks:

- Provide an **aerodynamic database** for the full flight domain of CALLISTO and for all vehicle configurations
  - Fin folded / unfolded
  - Landing legs folded / unfolded
  - Various thrust levels

Challenges:

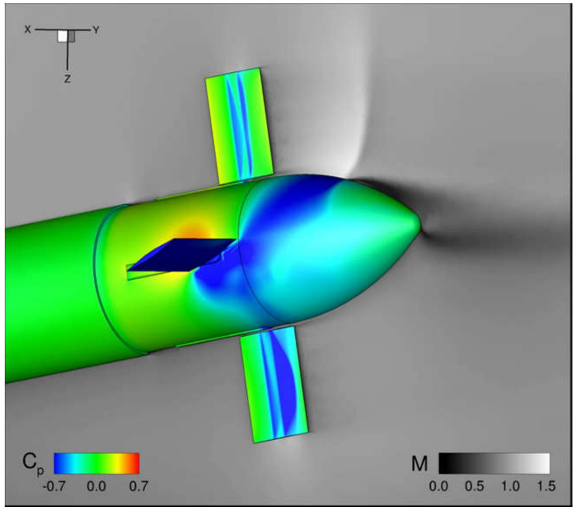
- **Very large flight domain** (AoA from 0° to 360°)
- CALLISTO is flying a long time in **transonic regions**
- High **accuracy** required

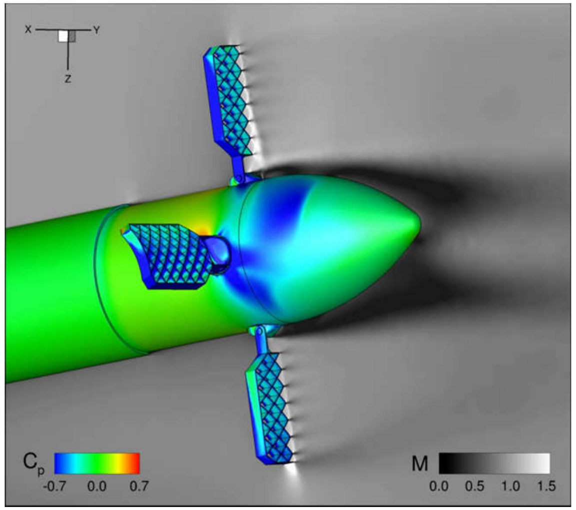
Configuration		Phase Applicable	Fins	Landing Legs	Thrust Plume
FFO (C0)		Ascent and Powered Tilt-Over: MEIG#1 – MECO#1	Folded	Folded	Thrust Plume
FFN (C1)		Ballistic MECO#1 – Fin Deploy	Folded	Folded	No Thrust Plume
UFN (C2)		Ballistic: Fin Deploy – MEIG#2 *and* Aerodynamic Descent: MECO#2 – MEIG#3	Unfolded (Deployed)	Folded	No Thrust Plume
UFO (C3)		Brake Boost: MEIG#2 – MECO#2 *and* Approach Boost: MEIG#3 – Legs Deploy	Unfolded (Deployed)	Folded	Thrust Plume
UUO (C4)		Landing: Legs Deploy – MECO#3	Unfolded (Deployed)	Unfolded (Deployed)	Thrust Plume + Ground Effect
UUN (C5)		Landed (Park): After MECO#3	Unfolded (Deployed)	Unfolded (Deployed)	No Thrust Plume + Wind Stability

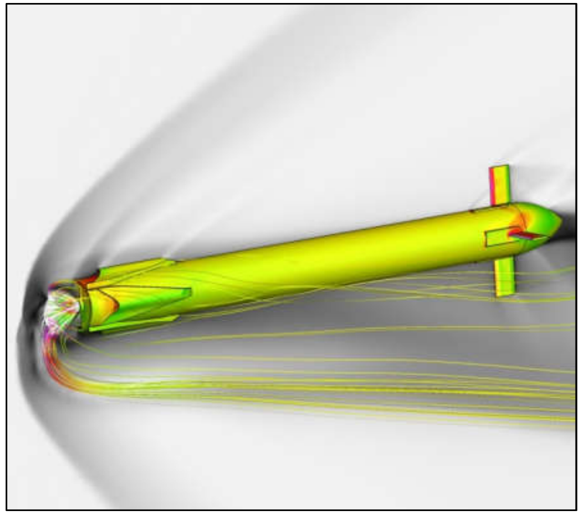
Aerodynamics (2/2)

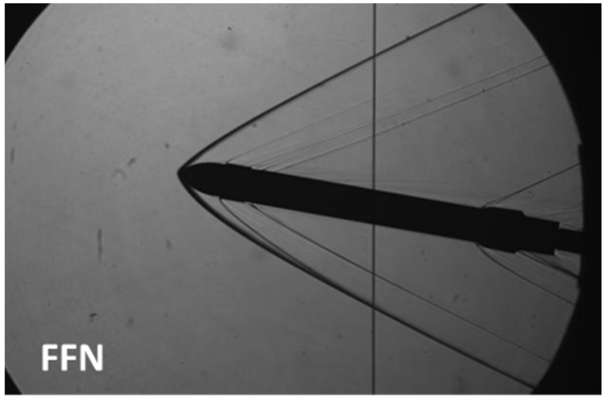
Solution approach:

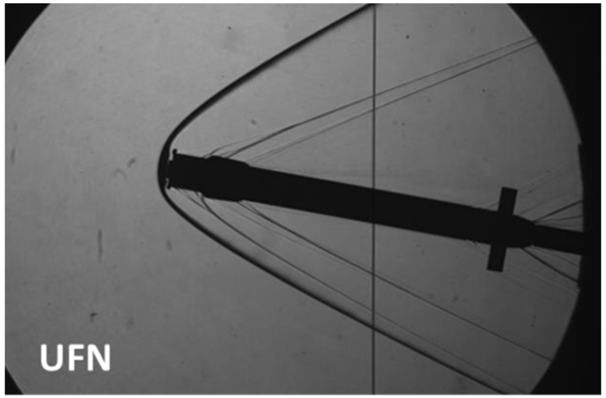
- **CFD computations** for the full flight domain with DLR TAU software based on high fidelity **Navier Stokes computations** and supported by trends based on Euler computations
- **Wind Tunnel Tests**
  - TMK in Cologne
  - Larger Wind Tunnels
  - VMK for data with retro-propulsion











Aerothermodynamic

Tasks:

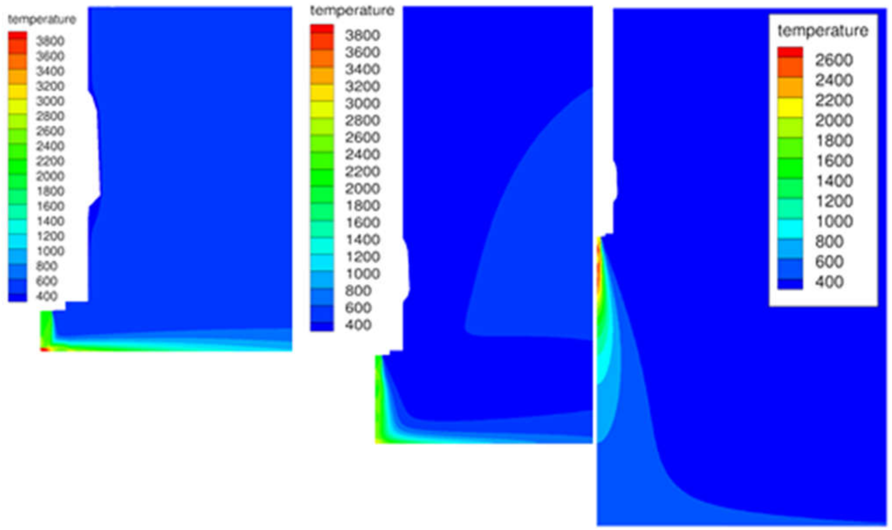
- Predict **aerothermal loads** on the vehicle to be able to size the TPS needed to make the vehicle **reusable**

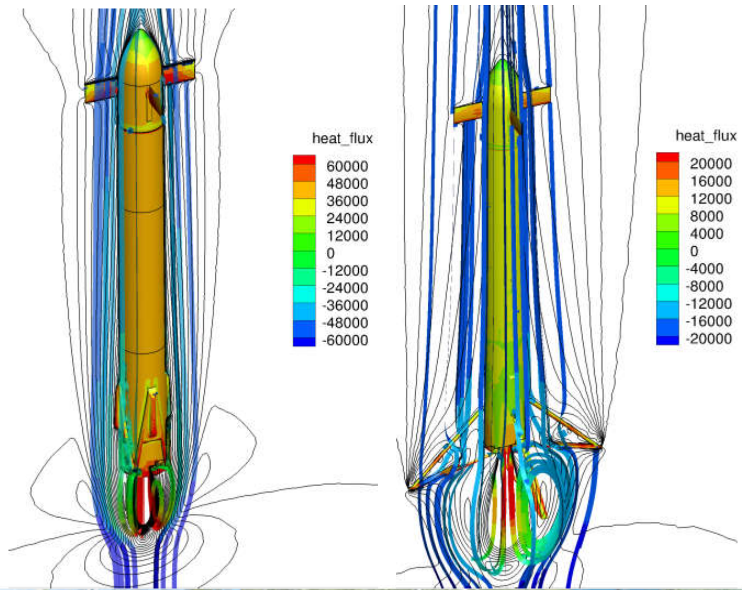
Challenges:

- Large number of configurations
- Understand **retro-propulsion** and especially the region close to the **base plate**
- Model properly the **interaction between ground and vehicle** for launch, landing and the phase after the landing

Solution approach:

- **Aerothermodynamic CFD** with DLR TAU software for design of TPS considering reusability requirement
- **WTT** in VMK for retro-propulsion
- Data from hot firing tests





Conclusion

JAXA, CNES and DLR are developing jointly CALLISTO to **pave the way for potential future reusable launch vehicle** in Europe and in Japan.

For that purpose numerous **key technologies** are being **developed and matured** in the frame of CALLISTO design and development phases.

By next ISTS in 2021, the **integration of CALLISTO** will have started in Tsukuba and **hot firing tests** in Noshiro will be under preparation.

Demonstration in flight of the **mastering of the key techniques and technologies** will start in 2022 from Kourou.

At ISTS 2023, we should be able to give a first glimpse in the results of the **post flights analysis** and the **lessons learned.**