CALLISTO: a Demonstrator for Reusable Launcher Key Technologies

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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

G&C: guidance & control
RCS: reaction control system
TVC: thrust vector control
TM/TC: telecommand and telemearure
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_\infty 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
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
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**.