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CALLISTO - Reusable VTVL launcher first stage demonstrator

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ABSTRACT:

DLR and CNES are jointly developing a demonstrator for a reusable vertical take-off vertical landing launcher first stage. It is called CALLISTO, which stands for “Cooperative Action Leading to Launcher Innovation in Stage Toss back Operations”. The CALLISTO project, benefiting from the long heritage and know-how available in Europe is pursuing two main goals. First it shall demonstrate the capabilities to perform the specific manoeuvres and operations needed for an operational reusable first stage performing return to launch site. Second, the repetition of flights will allow confirmation and refinement of the economic assumptions of system studies performed in preparation for the development of a future European launcher.

ABBREVIATIONS

ALS	Approach & Landing System
CALLISTO	Cooperative Action Leading to Launcher Innovation in Stage Toss back Operations
CDR	Critical Design Review
CFRP	Carbon Fibre Reinforced Plastics
CNES	Centre National d’Etudes Spatiales: French Aerospace Centre
DEMS	Demo & Experiment Measurement System
DGPS	Differential Global Positioning System
DLR	Deutsches Zentrum für Luft- und Raumfahrt: German Aerospace Centre
DRL	Downrange Landing
FRR	Flight Readiness Review
GNSS	Global Navigation Satellite System
HNS	Hybrid Navigation System
IMU	Inertial Measurement Unit
MRO	Maintenance, Repair and Operations
PDR	Preliminary Design Review
RAMS	Reliability, Availability, Maintainability and Safety
RTLS	Return to Launch Site
SRR	System Requirement Review
VTVL	Vertical Take-Off, Vertical Landing

1 INTRODUCTION

Reusability of a launcher first stage is expected to allow for a reduction of the launch service cost and a reduction of launcher environmental impact. In addition, it will strongly increase the operational flexibility of the launch vehicle. In order to find the optimal concept in the particular case of Europe with respect to know-how and accessible markets, it is vital that launcher design preparatory studies (see [1], [2], [3] and [4]) are validated and complemented by demonstration results to:

- refine the quality of these analyses and the assessment at technical and economic levels
- verify the accurateness of the assumptions
- test and demonstrate technological bricks at limited cost and risk

For this task DLR and CNES decided to join their forces. A common demonstration roadmap has been established to develop, build and test reusable vehicles and related critical components. This allows a significant increase of the organisational knowledge at a technical and economic level. This roadmap includes in particular a vertical take-off and vertical landing (VTVL) reusable subscale launcher first stage demonstrator. This vehicle is called CALLISTO, which stands for “Cooperative Action Leading to Launcher Innovation in Stage Toss back Operations”. Current research efforts on Vertical take-off and horizontal landing (VTHL) of reusable stage are covered by the DLR ReFEx (Reusability Flight Experiment) winged demonstrator [5]. A third important element of the joint DLR/CNES roadmap is the Prometheus reusable and low cost LOx/LCH4 engine [6], managed by ESA. The evaluation of the results of these demonstrators will then be implemented in a larger demonstrator which will be very close to an operational vehicle.

In the particular frame of the CALLISTO VTVL demonstrator, DLR and CNES want to achieve two main goals:

First, CALLISTO should allow to confirm and refine the assumptions considered in the wide range of studies at system level which were performed by DLR and CNES in order to prepare the launcher of the future. These studies consider a large variety of concepts with different propellants, staging, numbers of reuse, types of return method (winged or propelled), nominal performances, etc. see [1], [2], [3] and [4]. In particular, data gathered with CALLISTO will support analysis of VTVL concepts performing a return to launch site (RTLS) mission. Further the results can be extended for a down-range landing mission (DRL).

Second, CALLISTO allows testing and mastering technologies, as well as specific operations (in-flight and on-ground) at a reduced cost and risk. The total cost of the CALLISTO program is indeed only few percent of the development cost of an operational launch vehicle. The development of an operational Ariane class launcher would benefit from the lessons learned gathered during the CALLISTO demonstration program for the reusability of VTVL launch vehicle first stage.

The background and timeline of CALLISTO are presented in section 2. Section 3 describes the reference mission, the incremental demonstration logic and how the necessary know-how on first stage reusability will be gathered.

While CALLISTO‘s VTVL concept resembles similar concepts put into operational service by SpaceX or Blue Origin, it contains numerous aspects of technology development and demonstration which are more amenable in the European launcher environment. To develop, built, test CALLISTO and analyse the flight results, DLR and CNES will benefit from their long heritage and know-how in the field of aerodynamics, landing systems, propellant management, propulsion, lightweight structures, GNC and actuators, for both aerospace and aeronautics. These aspects will be discussed with more details in section 4. Finally section 5 broaches preliminary elements about ground segment and safety.

2 BACKGROUND AND TIMELINE

The idea to develop CALLISTO was first proposed in 2015. After a preparatory phase in 2016 (see [7]), the project progress has rapidly increased during the course of 2017 (see [8]) and reached a first milestone with the realisation of the phase A. During this phase, the goal was to confirm the feasibility of the concept to meet the demonstration objectives of the CALLISTO project. This phase was successfully concluded by a SRR (System Requirement Review) which took place in February 2018. During Phase B, the level of detail will be refined and the preliminary design of the system completed. It will allow confirmation of the technical specifications and completion of the product preliminary designs. A PDR (Preliminary Design Review) which is planned for late 2018 will conclude the phase B. After the PDR, an intermediate decision step will occur in order to confirm the goals of the cooperation and to prepare the realisation of the vehicle, as well as to select industrial partners. According to the current planning, phase C and D should take place in 2019 and 2020 with a first Flight Readiness Review (FRR). This lays the foundation for test flights during the course of phase D. The goal of these flights is to reduce risks before performing the full envelope flights which will occur during phase E after a second FRR. CALLISTO flight campaign should be completed in 2021, according to the preliminary timeline.

3 REFERENCE MISSION, REUSABILITY AND DEMONSTRATION LOGIC

3.1 Reference mission

In order to fulfil the goals of CALLISTO project, the reference mission must place the CALLISTO vehicle in conditions similar to those of an operational launcher reusable first stage. This includes performing a return to the launch pad manoeuvre with the toss-back method. Contrary to other vehicles, such as Space X Grasshoper or Blue Origin New Shepard, CALLISTO is designed to perform a non-vertical flight with large attitude changes during its nominal reference flight. The mission contains:

- a propelled ascent phase with final conditions similar to those of an operational launcher in tern of flight path angle and dynamic pressure

- a large change of attitude followed by a boost to modify the direction of the velocity vector to enable a return towards the launch range
- an optional re-entry boost to decrease the re-entry velocity
- an aerodynamically controlled and guided re-entry with transition from supersonic to subsonic regime
- a landing boost allowing touch down on the targeted landing area with accuracy and a low velocity which can be absorbed by the landing system. The vehicle then reaches a stable position on the ground and can be passivated.

Possible trajectories are studied with consideration of high level constraints such as safety and operation constraints at the launch place and hardware availability for a first flight in late 2020. In particular a critical component of the vehicle is the about 40 kN LOx/LH2 re-ignitable rocket engine with a large range of continuous throttling capability. The selected engine needs to be able to throttle down to a level of under 40% of the maximum thrust. This capability is particularly important for the landing during which the thrust to weight ratio should be kept at an acceptable level. Both the lowest and highest thrust levels reached by the engine at sea level limit the mass of the demonstrator at lift-off and at landing.

For what concerns the safety constraints, the difficulty comes from the fact that in addition to the risks linked to the ascent, the descent of the vehicle can endanger existing facilities and populations around the launch and landing site. Modification of the trajectory allows mitigating some of the risk but may come at the cost of a reduction of the reachable flight domain.

An example trajectory, verifying the aforementioned high level constraints, is shown in Fig. 1. The reference trajectories consist of an ascent at the end of which a down range of several kilometres is reached. It is followed by a so called PTO (powered tilt-over). During this phase a large attitude change is performed with the help of the main engine gimballed in the appropriate direction. Preliminary analyses show that under certain conditions a PTO could bring better performance than a manoeuver relying only on RCS (reaction and control system) thrusters. Once CALLISTO has been redirected towards the landing area, the main engine is disengaged. During the ballistic phase following this event the apogee is reached and the attitude of the vehicle is modified in preparation for an optional re-entry boost. This boost allows the demonstration of the capability to re-ignite the main engine after a large change of attitude and with the nozzle exit facing in the direction of movement. After this, an unpowered, aerodynamically controlled and guided phase follows. For this purpose, deployable aerodynamic surfaces are used. The flight ends with a last boost reducing the velocity to a level compatible with the energy absorption capability and the dynamic properties of the landing system.

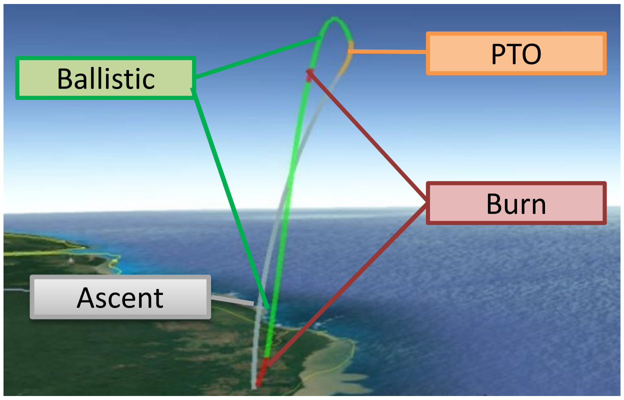

Figure 1. Candidate reference trajectory

3.2 Incremental demonstration logic

The reference trajectory contains a large number of manoeuvres and events to be demonstrated which are specific to reusable VTVL vehicles performing a return to launch site (RTLS). In order to reduce the risks linked with a too large number of new demonstration goals at each flight, an incremental demonstration logic is being prepared. By doing so the knowledge of the vehicle characteristics is improved at each flight, making the next flight with more demanding conditions a smaller step to overcome. For that purpose, a preliminary estimation resulted in a need for a total of at least 5 flights. Among these 5 flights at least 2 should perform the reference mission. The three other flights should take place, first with demonstration goals targeting a reduction of risks and in particular helping mitigating the risk level for the two last flights. Note that a total of more than forty manoeuvres and events of interest have been identified. For each of them the possibility to include it in one of the five flights will be assessed with consideration of associated risks and gains. In particular first flights will be limited to vertical flights or small down-range landing with limited mechanical and thermal loads. The deployment of landing legs and aerodynamic control surfaces will also be tested incrementally. During the first flight for instance the launch will take place with landing legs already unfolded. Other aspects worth to be mentioned is the fact that the thrust to weight ratio at landing will be incrementally increased with first hovering capability with the goal to at the end land with thrust level noticeably exceeding the weight. Analysis performed on future European launcher with a reusable first stage [1] showed important performance advantages when using larger thrust levels. Both during ascent and descent using large thrust level allows a reduction of the duration to provide a given ΔV and therefore allows reducing the work of the gravitation.

3.3 Reusability

While on one side performing the manoeuvres and flight phases described in the previous sections 3.1 and 3.2 is a major aspect of the CALLISTO demonstration objectives another one is to study reusability both at technological and operational levels. The goal for an operational vehicle is of course to minimize the effort between flights. This has consequences on the time and cost to re-prepare the vehicle and at the end impact strongly the competiveness of the vehicle on the world market. In order to gather know-how in this domain, CALLISTO will be monitored during flights and inspected after landing to understand precisely what happens and what can damage components. See section 4.9 for more information on this aspect.

The results will be derived at the end into technological know-how to optimize the design of the different components. Technologies and component designs providing a good confidence to survive several flights without being repaired or requiring extensive inspection effort between flights will help to achieve the competiveness target. The related known-how, which cannot be gathered with on-ground tests, will then be used to limit risks and optimize the design of future operational vehicles.

From on operational point of view, flying and re-flying CALLISTO will allow testing and optimizing MRO (maintenance, repair and operations). Procedures to recover, inspect and repair the vehicle when needed will be tested and improved. The MRO efficiency strongly impacts the economic competiveness of the vehicle. Keeping the operation simple and limiting the required ground means and efforts is considered in the design of CALLISTO. For instance sensors will help monitoring the loads encountered by the components. As different flight profiles will be flown, it will be possible to study the effect of the different manoeuvres and derive flight strategy limiting the damage on the vehicle. The ultimate goal is of course to avoid disassembling the vehicle after each flight to check the health of the components or even replace them.

The know-how about reusability will be used to validate or improve if necessary the analysis at system level performed both at DLR and CNES and presented in [1], [2], [3] and [4].

4 VEHICLE DESIGN

4.1 Overview

CALLISTO is characterised by an aspect ratio compatible with operational launcher first stages. However the scale would be one third to one fourth, see Fig. 2. It is propelled by a unique 40 kN class rocket engine using liquid oxygen (LOx) and liquid hydrogen (LH2). The propellants are stored in integral tanks with separated bulkheads. Depending on the throttling level, the mixture ratio will vary around the value 6. The continuous throttling ability is a key feature of the demonstrator. Even if the modest dimensions of the CALLISTO demonstrator imply a relatively high ratio between dry mass and propellant mass, a large and quick throttleability is vital to perform landing without excessive surplus of thrust with respect to weight.

Figure 2. CALLISTO layout

In the current baseline configuration, CALLISTO is equipped with three different flight control systems which will be used alone or in combination during the different phases of flight:

- the engine which can be gimballed and throttled.
- the RCS which can control roll when the engine is on but also perform attitude change manoeuvres on its own.
- four aerodynamic control surfaces, used exclusively for the descent and deployed to provide roll, pitch and yaw control, as long as the dynamic pressure is high enough. The aerodynamic control surfaces will also be used to trim the vehicle in order to fly with a given angle of attack and provide some lift.

The aerodynamic control surfaces are not the only deployable equipment added in comparison to an expendable launch vehicle. Four pneumatically deployed landing legs are used to absorb the remaining kinetic energy during landing and therefore reduce loads on the rest of the vehicle.

A noticeable difference with a future operational reusable first stage is the presence of a fairing on the top of the vehicle. This fairing is needed for the ascent of CALLISTO, but is not advantageous for the descent as it reduces the drag both during ascent and descent. On an operational vehicle, no fairing is required, as in place of the fairing the operational reusable first stage would support an upper stage through an interstage structure.

4.2 Aerodynamic aspects

A defining characteristic of a VTVL vehicle is the fact that during the mission, particularly large ranges of angle of attack are encountered. During the ascent at zero-lift, the angle of attack is differing from zero only when a perturbation modifies the air flow. During the descent the angle of attack is close to 180°. The descent is however not performed completely at zero lift. Indeed as the propellant loading of the vehicle is strongly lower than during the ascent, it is acceptable without significant impact on the structure to generate lift with an angle of attack. The angle of attack is then maintained with aerodynamic surfaces. The knowledge of the flight qualities of CALLISTO is therefore required on a range of angle of attack starting below 0° and extending above 180°. The preliminary determination of the aerodynamic characteristics of CALLISTO has been performed with the help of Euler and Navier-Stokes CFD analyses, to cover a large range of flight conditions and provide a good level of accuracy when needed. In particular for the aerodynamically controlled descent, uncertainties on the flight qualities have a large influence on the reachable flight envelope and require an extra attention. An example of CFD results for the aerodynamically controlled part of the descent is shown in Fig. 3. During the propelled part of the flight the thrust is usually much larger than the aerodynamic force reducing the influence of aerodynamic uncertainties. The propelled part of the descent is an extreme case, as the modification of the flow around the vehicle by the exhaust gases decreases the aerodynamic drag to level negligible compared to the thrust. In order to complete the CFD analysis, wind tunnel tests are already in preparation.

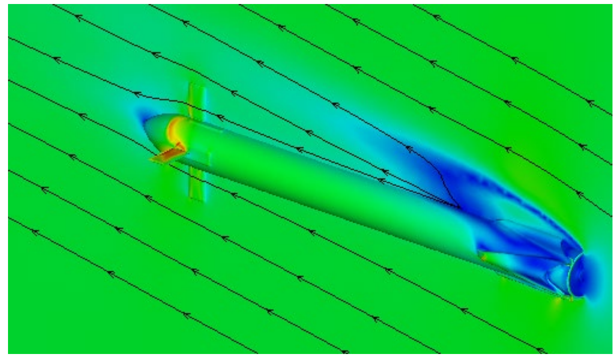

Figure 3. Example of Mach distribution during the non-propelled descent (angle of attack 170°, M=0.9)

4.3 Aerothermal aspects

The aerothermal aspect of the CALLISTO vehicle is a significant field of investigation. One key difference between a reusable full size launcher like Falcon 9 and CALLISTO is the relatively low ballistic Mach number throughout the trajectory but also specifically during the retro-propulsive phase. This means that almost all design driving thermal loads are due to the hot exhaust plume, as well as possible radiation on the landing pad.

For the purpose of phase A, several possible configurations were investigated using computational fluid dynamics (CFD) methods.

All investigations were performed with DLR-Navier-Stokes solver TAU, which is validated for a wide range of steady and unsteady sub-, trans- and hypersonic flow cases. The applied models for thermodynamic and transport properties are based on a non-reacting mixture of two thermally perfect gases (air and engine exhaust gas) along the entire retro-propulsion trajectory, similar to previous studies on supersonic retro-propulsion [1], [9] and [10].

The heat flux and flow field temperature for a reference trajectory point for three of the considered configurations of phase A is shown in Fig. 4. As can be seen, the highest heat fluxes are mainly in the region of the aft bay and on the exposed structures like legs and fins. Moving the legs closer to the tail structures results in a beneficial impact on the thermal loads on lower part of the vehicle. Additionally, the landing leg structure protects the aft bay structure.

The development of the plume extension, as well as the heat flux on the walls is illustrated in Fig. 5. Unlike Falcon 9, or the studies presented in [1] and [10] the plume remains relatively concentrated at the aft end of the vehicle, and while heating the air around the spacecraft only very low fractions of actual exhaust gas enclose the vehicle.

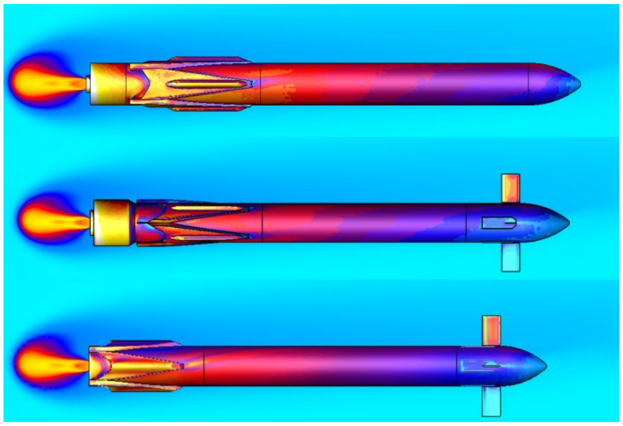

Figure 4. Heat flux during propulsive re-entry phase for three of the considered configurations. (angle of attack = 175°, M = 0.7)

Current efforts for phase B focus on evaluating the impact of the turbulence modelling as well as the hydrogen/oxygen combustion on the design critical heat fluxes. Further the loads during touch down and engine shut down are evaluated.

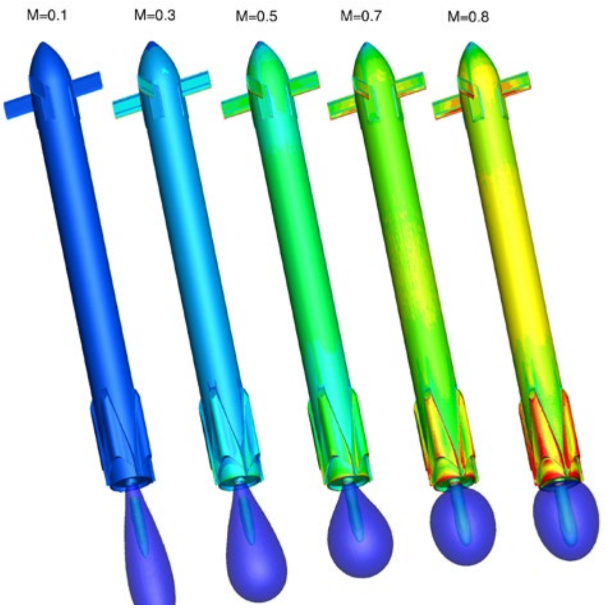

Figure 5. Heat flux during propulsive re-entry phase. Heat flux given for uniform temperature T_w = 300 K

4.4 Aerodynamic control surfaces

The design of the aerodynamic control surface system is a challenge by itself. Even though it is relatively small, it provides the only means of control during the unpowered descent. Now this phase has a very strong impact on the final landing accuracy. Therefore this system is critical as it allows controlling the vehicle and in particular its attitude and guide the trajectory towards the landing area.

The aerodynamic control surface system is made out three different parts: the aerodynamic profile, the deployment system and the actuators. The requirements on performance, reliability and mass are high to guarantee the success of the flights.

However the sizing of these components depends heavily upon inputs that are typically not known with precision in early design stages, e.g. maximum aerodynamic forces and torques, as well as needed bandwidth of the aero-surface deflection angle control loop. Especially the last point can only be derived once the outer control loops of guidance and navigation are designed, that themselves depend upon vehicle configuration, mass, centre of gravity, inertia, trajectory and aerodynamic properties.

To solve this interdisciplinary design problem an iterative process is applied.

4.5 Approach & Landing System Architecture and Design

The purpose of the Approach & Landing System (ALS) is to provide the following top level functions:

- absorb the residual kinetic energy
- provide static and dynamic stability
- maintain adequate ground clearance between engine nozzle exit plane and ground
- protect the vehicle body against structural overload and landing shocks.

These functions are realized through the attachment of landing legs to the vehicle body. The landing legs and the vehicle body jointly form the landing system. The baseline architecture features a 4 legs design with inverted tri-pod style landing gear (see Fig. 6 and Fig. 7). A fairing element is foreseen to reduce aerodynamic impact of the legs during ascent/descent and protection of the primary strut and pneumatic actuation system. The structural parts are mainly made from titanium and CFRP (Carbon Fibre Reinforced Plastics). Energy absorption is realized through intended plastic deformation of dedicated load limiting elements (energy absorbers). The ALS is equipped with flight instrumentation sensors for health and usage monitoring. The ALS operation starts with the approach phase at the approach gate ~100 m above the landing pad and ~6 s of flight time remaining before touchdown. Launch locks are fired and the leg assembly is deployed. The landing phase begins with main engine cut-off and includes the final touchdown until the vehicle comes to a rest. Thereby, vehicle landing stability, ground clearance and energy absorption are therefore the result of the overall vehicle landing dynamics and kinematics of the landing gear architecture. Ultimately, the landing system shall enable a safe transition from flight to ground state. Touchdown dynamics is additionally influenced largely by other system and operational factors such as engine trail-off characteristic, wind and gust situation and the surface conditions at the landing zone.

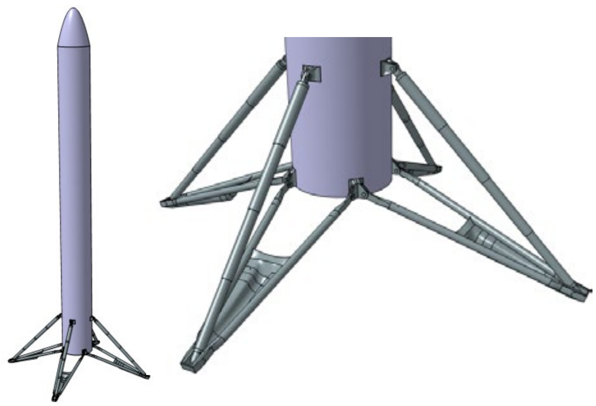

Figure 6. Four legs, inverted tripod architecture with attachment at vehicle's aft bay. Landing gear in deployed configuration

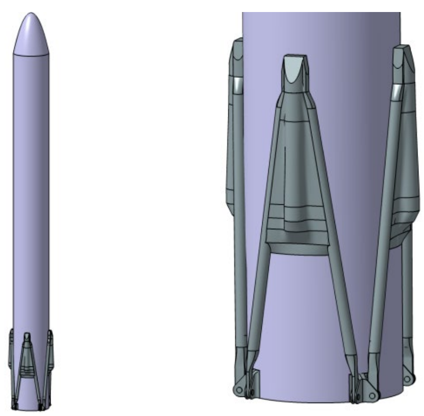

Figure 7. Landing gear in stowed configuration

Main areas of research and technology development covered by the ALS design, development, verification and flight test are:

- Landing dynamics – understanding the interaction of various vehicle systems and operational factors during approach and landing. Modelling and simulation of the approach and landing phase to enable simulation based and supported development and qualification.
- Technology development such as implementation of structural health and monitoring concepts and use of advanced materials such as fibre-ceramic hot structures.
- Reliability, availability, maintainability and safety (RAMS) aspects such as landing gear reliability and touchdown safety. The investigation of inspection and repair concepts including health monitoring techniques is of interest to understand life cycle costs of an operational system.

For all these aspects the CALLISTO joint project team will rely on the long European experience in terms of landing dynamic simulation, test and design [11], as for instance for planetary landers [12].

4.6 Guidance, Navigation and Control

Very precise Guidance, Navigation and Control (GNC) system is required during the whole trajectory of CALLISTO in order to stay on an optimal trajectory and limit the propellant required for the return to launch site. In particular, recovering CALLISTO on the landing zone at the end of each flight is only possible if the position, velocity, attitude and angular velocities are known and controlled very accurately.

In particular for navigation, an improved version of DLR's Hybrid Navigation System (HNS) already used on SHEFEX II [13] and planned for SHEFEX III [14] will be used. Long-term accurate navigation is achieved by combining both high-frequency measurements from inertial sensors and measurements from non-inertial sensors. The HNS will be equipped with an in-house built inertial measurement unit (IMU) consisting of four commercial off the shelf accelerometers and four gyroscopes in a tetra-axial pattern. The HNS will also rely on GNSS (Global Navigation Satellite System) sensors enhanced with DGPS (Differential Global Positioning System).

4.7 Propellant management

The reference mission of CALLISTO comprises several ballistic or non-propelled phases, as well as two large attitude manoeuvres making the design of the propellant management system particularly challenging. Even though Europe, especially Germany and France, have a long and successful experience with LOx and LH2 propellant management, rapid in-flight re-ignition after a large attitude change has not been demonstrated yet, but needs to be mastered to perform a RTLS mission. Therefore the propellant temperature and pressure have to be tightly controlled, during the whole flight and sloshing has to be limited. In particular at large attitude changes, the propellant tends to slosh and to wet part of the tank wall which have increased in temperature after being uncovered, as the tank empties. While entering in contact with these hot walls, the cryogenic propellant vaporizes. At the same time movements of the propellant tend to homogenize its temperature. An efficient propellant management system is necessary to avoid that the propellant temperature and pressure end up outside of the allowable range for the engine. In addition, it has to be guaranteed that when the engine is reignited directly at the end of the manoeuvre only liquid propellant will be pumped to avoid damaging the engine. This can be achieved with an anti-sloshing device, which allows damping of the sloshing movement and keeping propellant at the tank outlet. The design and optimization of the anti-sloshing system is based on CFD analyses. In addition to the numerical analysis experimental studies will be performed. These analyses allow determining the level of perturbation on the vehicle attitude which results from propellant movements. Sloshing may disturb attitude change manoeuvre or controllability of the CALLISTO vehicle for instance during the critical landing phase.

4.8 Structure and mass

The small size of CALLISTO has the advantage of limited costs and risks. However it also requires careful mass budget allocation. Every additional kilogram has a sizeable impact on the flight envelope that can be reached. Therefore final mass is an important factor for design of the structure and components. As mentioned in section 4.1, a lightweight integral tank solution has been selected. Main structures will be built out of carbon fibre reinforced plastics (CFRP), aluminium or titanium. In addition the incremental demonstration logic (see section 3.2) will allow to incrementally reduce reserves in order to improve the performances and consequently increase the flight envelope of CALLISTO. The design of the different structure is computed and optimized with FEM (finite element method) to reach the best performance, as shown for instance in Fig. 8.

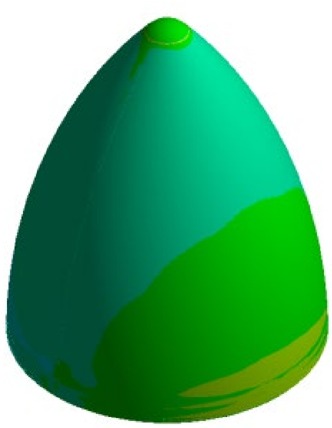

Figure 8. Example of computed stress repartition on the fairing by FEM

4.9 DEMS

One core need of CALLISTO is to help Europe's space transportation community in risk mitigated development of an operational VTVL stage. Therefore it is mission-critical to collect data all along mission preparation, flight itself and Maintenance, Repair & Overhaul (MRO) operations as well.

The CALLISTO team is convinced that special care has to be given to the Demo & Experiment Measurement System (DEMS) on-board the Vehicle.

According to ELV developed and/or operated in Europe for decades, there are four classes of measurements and information to be retrieved all over a CALLISTO mission (ground and flight phases).

1) Safety (of flight) data (class #1): MUST data to be retrieved during flight for ensuring that safety officer(s) on ground may disable the vehicle as soon as flight conditions get beyond safety range (or corridor);
2) ELV regular Flight Data (class #2): data which is helpful for getting proper proof that mission was completed successfully. Post-flight analysis relies on this set of data for especially deriving lessons learned;
3) Flight Test Instrumentation (class #3): this set of measurement devices is used for qualification flights only prior to commercial operations of a brand new launcher or a major change to the baseline architecture. In case of CALLISTO there is no reason to get the distinction in between this class and previous one;
4) DEMS (class #4): set of measurements in addition to 3 previous classes: data beyond information of previous classes which would be useful in risk mitigation for the development of a future VTVL reusable launcher stage. It may be not specific measurement devices when compared to previous classes but rather more demanding specification in terms of for instance measurement range, accuracy, sample rate...

Fig. 9 provides indication how these four classes interact with each other.

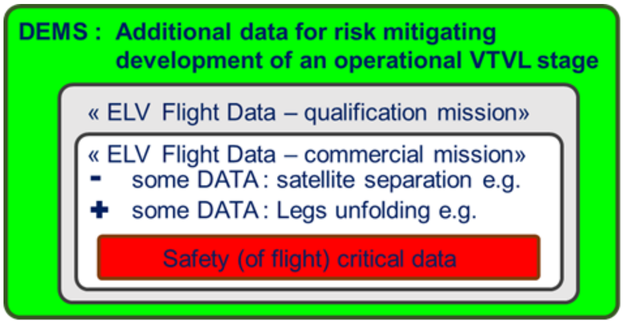

Figure 9. Set of 4 measurement classes to be on board CALLISTO and retrieved

5 GROUND SEGMENT AND SAFETY

The ground segment for CALLISTO encompasses the following segments:

- Infrastructure: vehicle preparation hall, take-off area and landing zone, as well as propellant storage area
- Ground support equipment: mechanical, electrical, fluidics
- And last but not the least, safety range material namely radar and telemetry / telecommand control stations.

According to specific features of the CALLISTO project, primary design drivers for its ground segment are:

- Flight operations period which will last some months in total ;
- The objective to recover the vehicle and get it flying again quite rapidly from and to an operational flight centre ;
- Weather conditions: on ground and in altitude as well.

From first design driver, it may be derived that temporary installations or existing installations which are currently decommissioned have to be favoured.

As soon as an automated vehicle has to be recovered on ground (second design driver); then features of the airborne Flight Neutralization System require a special attention. In case of CALLISTO, option in between mid-air vehicle destruction or recovery of disabled vehicle in one piece is not yet traded-off.

Last but not the least, weather conditions will even have a stronger impact on ground segment design when compared to an operational space transportation system that is supposed to be more or less insensitive to normal weather conditions along the calendar year (beside wind conditions in altitude). For the sake of comprehension, assuming that CALLISTO is operated from French Guiana with two very different seasons (dry and rain seasons), the question whether it would make sense to build a devoted paved road for reaching the landing area in case that operations would be conducted over the rain season has to be answered.

6 CONCLUSION & OUTLOOK

Within the CALLISTO project, DLR and CNES are joining their force and experience to develop, build and test a demonstrator of a vertical take-off vertical landing launch vehicle reusable first stage. CALLISTO, which is part of the CNES and DLR common RLV roadmap, is going to demonstrate over the course of several test flights the mastery of the manoeuvres contained within a return to launch site mission. During these flights and related ground operations numerous data will be collected and used to optimise the potential development of an operational Ariane class launch vehicle with a reusable first stage. In addition these data will be the basis on which CNES and DLR will validate and refine their RLV system analysis.

The fundamental feasibility of CALLISTO has been shown during the phase A of the project. Phase B which started in March 2018 is set to continue during the course of 2018. This phase concentrates on the design of the different products in preparation for the manufacturing phase.

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8 BIBLIOGRAPHY

[1] Dumont, E., Stappert, S., Ecker, T., Wilken, J., Karl, S. Krummen, S. & Sippel, M. (2017): Evaluation of Future Ariane Reusable VTOL Booster Stages, IAC-17-D2.4.3, 68th International Astronautical Congress (IAC), Adelaide, Australia, 25-29 September 2017. [http://elib.dlr.de/114430/]

[2] Sippel, M., Stappert, S., Bussler, L. & Dumont, E. (2017) Systematic Assessment of Reusable First-Stage Return Options, IAC-17-D2.4.4, 68th International Astronautical Congress (IAC) Adelaide, Australia, 25-29 September 2017. [http://elib.dlr.de/114960/]

[3] Vila, J. & Patureau de Mirand A. (2017) Weighting options for the next generation of Ariane launchers IAC-17- D2.4.2, 68th International Astronautical Congress (IAC), Adelaide, Australia, 25-29 September 2017.

[4] Stappert, S., Wilken, J., Sippel, M., Dumont, E. & Dietlein, I. (2018), Assessment of a European Reusable VTOL Booster Stage, SP2018_00478, Space Propulsion 2018, Seville, Spain, 14-18 May 2018.

[5] Bauer, W., Rickmers, P., Kallenbach, A., Stappert, S., Schwarz, R., Sagliano, M., Häseker, J., Flock, A., Thiele, T., Bierig, A., Windelberg, J. & Ksenik, E. (2017), Upcoming DLR Reusability Flight Experiment IAC-17-D.2.6.1, 68th International Astronautical Congress (IAC), Adelaide, Australia, 25-29 September 2017. [http://elib.dlr.de/116879/]

[6] Ianetti, A., Girard, N., Tchou-kien, D., Bonhomme, C., Ravier, N. & Edeline, E (2017). PROMETHEUS, a LOx/LCH4 Reusable Rocket, Engine, DOI: 10.13009/EUCASS2017-537, 7th European Conference for Aeronautics and Space Sciences, Milan, Italy, 3-6 July 2017.

[7] Baiocco, P., Louaas, E., Bourgeois, E., Bonnal, C. & Bouilly, T. (2016) Reusable rocket stage experimental vehicle and demonstration. IAC-16-D2.6.6, 67th International Astronautical Congress (IAC), Guadalajara, Mexico, 26-30 September 2016.

[8] Tatiossian, P., Desmariaux, J. & Garcia M. (2017) : CALLISTO Project - Reusable first stage Rocket Demonstrator, DOI: 10.13009/ EUCASS2017-680, 7th European Conference for Aeronautics and Space Sciences, Milan, Italy, 3-6 July 2017.

[9] Ecker, T., Karl, S., Dumont, E., Stappert, S. & Krause, D. (2017) A Numerical Study on the Thermal Loads During a Supersonic Rocket Retro-Propulsion Maneuver. 53nd AIAA/SAE/ASEE Joint Propulsion Conference, 2016. 53rd AIAA/SAE/ASEE Joint Propulsion Conference, Atlanta, USA, 10.-12. June 2017. DOI: 10.2514/6.2017-4878 [http://elib.dlr.de/111762/]

[10] Ecker, T., Zilker, F., Dumont, E., Karl, S. & Hannemann, K. (2018) Aerothermal analysis of reusable launcher systems during retro-propulsion Reentry and landing, SP2018_00040, Space Propulsion 2018, Seville, Spain, 14-18 May 2018.

[11] Witte, L. (2015) Touchdown Dynamics and the Probability of Terrain Related Failure of Planetary Landing Systems - A Contribution to the Landing Safety Assessment Process. Dissertation, University of Bremen. [http://elib.dlr.de/102482]

[12] Buchwald, R., Witte, L. & Schröder, S. (2011) Verification of Landing System Touchdown Dynamics – A Status Report of a German Joint Co-operative Team on Landing Technology, IAC-11-A3.1.3, 62nd International Astronautical Congress (IAC), Cape Town, South Africa, 3-7 October 2011. [http://elib.dlr.de/106240/]

[13] Theil, S., Schlotterer, M., Hallmann, M., Conradt, M., Markgraf, M. & Vanschoenbeek, I. (2008): Hybrid Navigation System for the SHEFEX-2 Mission, AIAA Guidance, Navigation and Conference and Exhibit, Honolulu, USA, 18-21 August 2008. DOI: 10.2514/6.2008-6991. [http://elib.dlr.de/57209/]

[14] Samaan, M. & Theil, S (2013): Development of a Hybrid Navigation System for the Third Sharp Edge Flight Experiment (SHEFEX-3), The Astrodynamics Specialist Conference, Hilton-Head Island, USA 11-15 August 2013. [http://elib.dlr.de/85082/]