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Overview of the CALLISTO Project

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This paper describes an overview of the technology demonstration project called CALLISTO. JAXA, CNES, and DLR, based on equal partnership, have jointly performed system and project definition activities for a scaled reusable vertical take-off and vertical landing (VTVL) demonstrator vehicle called CALLISTO. The objective of the CALLISTO project is to obtain the data of flights and ground operations to verify the feasibility and potential interest of a future reusable VTVL first stage. The overall goal is to demonstrate the capability to recover a vehicle in toss-back (or boostback) and vertical-landing modes as well as turnaround operations linked to refurbishment and reuse. An overview of the project is given on mission requirements, project organization, development and test plan, vehicle, and mission profile in the present paper.

Key Words: CALLISTO, reusability, demonstrator

1. Introduction

Reusability of launch vehicles is a potential measure to substantially reduce launch service costs and open up new possibilities for space. JAXA, CNES, and DLR have shared the common view that a reusable vertical take-off and vertical landing (VTVL) first stage is a promising concept as the first step of reusability. Based on this view, the three agencies have performed joint activities for a scaled reusable VTVL demonstration vehicle to master key technologies to recover reusable first stages and to reuse them. This demonstrator will pave the way leading to future launch vehicles after Ariane 6 in Europe and H3 in Japan.

The technology demonstration project is called CALLISTO, which stands for Cooperative Action Leading to Launcher Innovation for Stage Toss-back Operations. The Phase-A feasibility study was kicked off in June 2017 and completed in March 2018. Since then, preliminary system and project definition study has been continued as the Phase-B activity to the present. The system in the CALLISTO project consists of the vehicle itself and the ground segment to operate it.

This paper presents a broad overview of the CALLISTO project. The interested reader is referred to Ref. 1) for a further overview of the CALLISTO vehicle and mission design and Ref. 2) for key technologies needed for a future reusable VTVL first stage and development status.

2. Project Objective and Mission Requirements

The objective of the CALLISTO project is to obtain the data of flights and ground operations to verify the feasibility and potential interest of a future reusable VTVL first stage.

The overall goal is to demonstrate the capability to recover a vehicle in toss-back (or boostback) and vertical-landing modes as well as turnaround operations linked to refurbishment and reuse with the aim to explore the overall mission cycle of a reusable first stage.

The mission requirements on flights are defined as: the vehicle shall

- Land on a designated landing platform, following a flight sequence including: a propelled ascent phase and a return phase including a boostback maneuver and a reentry phase such that the transonic region is crossed.
- Demonstrate the capability to perform the following sequence covering the flight conditions experienced by an operational reusable VTVL first stage: attitude maneuver at low dynamic pressure and minimized propellant re-conditioning duration.
- Perform a landing boost with a minimum non-gravitational acceleration of 1.3 g at least during one flight.

A landing with a non-gravitational acceleration of more than 1g (this means that the engine thrust is greater than the force of gravity) is an important technique to save amounts of propellants.

3. Vehicle Description

The CALLISTO vehicle is being designed to have a capability to reach the supersonic region using a single rocket engine and to return to the ground or a platform on the sea for reuse to meet the mission requirements. The vehicle size and mass are summarized in Table 1.

Table 1. Vehicle size and mass.

Item	Value	Unit
Diameter	1.1	m
Total height	13.5	m
Dry mass	1520	kg
Take-off mass	3600	kg

Figure 1 shows the vehicle configuration with the aerosurfaces (or fins) and the landing legs deployed. The landing legs remain folded during the majority of a flight and are deployed just before landing. The effectors for attitude control including the aerosurfaces are as follows:

- Four aerosurfaces driven by four electro-mechanical actuators,
- Thrust Vector Control (TVC) system by gimbaling the engine with two electro-mechanical actuators,
- Reaction Control System (RCS) composed of four hydrogen peroxide (H2O2) thrusters.

The aerosurfaces are also folded during ascent, but they are deployed at a high altitude and a small dynamic pressure in preparation for a reentry flight where the vehicle bottom is in the windward. They are used to stabilize and change attitudes during an unpowered reentry phase and probably an early powered landing phase to augment TVC control moments. Planar fins are shown in Fig. 1, but a trade study is underway between planar fins and grid fins as applied to Falcon 9. The RCS thrusters as well as the aerosurfaces are installed at an upper position of the forward (or upper) fuselage called Vehicle Equipment Bay (VEB).

The rocket engine for CALLISTO is shown in Fig. 2. The propellants are liquid hydrogen and liquid oxygen. JAXA developed an experimental small engine generating a thrust of 40kN at the sea level and demonstrated reusability over more than 100 times in a previous research activity.[3)] This engine is dubbed RSR (Reusable Sounding Rocket) engine. The engine for CALLISTO is equivalent to RSR engine, but JAXA will redesign and newly manufacture an improved engine (dubbed RSR2 engine) whose thrust increases by 10% and whose envelope and mass are reduced to be fitted to the CALLISTO vehicle. In addition to reusability, these engines have throttling and re-ignition capabilities as distinguished characteristics. RSR2 engine can modulate thrust continuously between 16kN and 44kN at the sea level.

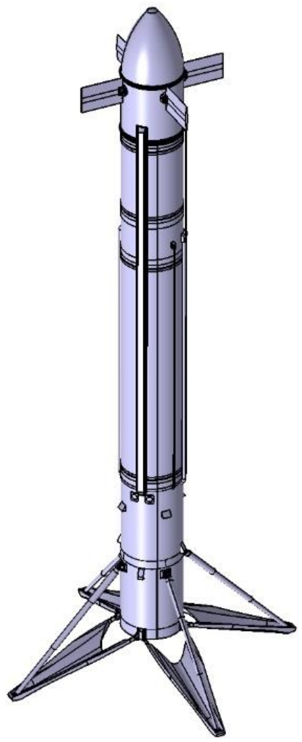

Fig. 1. Vehicle configuration.

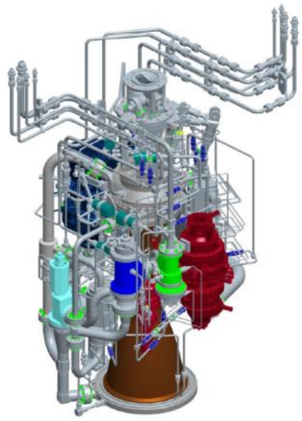

Fig. 2. Engine.

4. Project Organization

JAXA, CNES, and DLR formed a joint team to promote the development of the CALLISTO system. The joint team is organized based on equal partnership, and project management leaders and technical leaders are shared among the three agencies. Managing the CALLISTO project is a challenging task, because the three agencies are geographically separated, and technical backgrounds are very different among joint team members. Through two-year joint activity, we have learned frequent face-to-face meetings are very effective for mutual understanding and progress in technical activities.

The work sharing among the three agencies has been defined considering each agency's technical interests. Figure 3 shows the main elements of the CALLISTO system and development responsibilities for each element. As mentioned above , JAXA is responsible for the engine. All flights of the CALLISTO vehicle will take place inside or in the proximity of Guiana Space Center (CSG) managed by CNES, and therefore CNES is responsible for the ground facilities.

One of key technologies in the CALLISTO project is guidance and control. All the three agencies are interested in guidance and control software, and so two versions of guidance and control software will be developed and flight-tested: one by CNES while the other jointly by JAXA and DLR.

5. Development and Test Plan

JAXA has developed a precursory vehicle called RV-X (Reusable Vehicle-Experiment) prior to CALLISTO. RV-X is also a VTVL vehicle equipped with RSR engine. The flight tests of RV-X are planned in 2019 in Noshiro Rocket Testing Center of JAXA. RV-X, which has been developed by JAXA and industrial partners in Japan, is outside the scope of the CALLISTO project but is expected to provide critical data for the design of CALLISTO. For example: propulsion system characteristics such as helium pressurization and consumption data and vibration environment data during engine combustion.

The CALLISTO vehicle is broke down into some modules for development. The modules assembled in Europe will be transported to Japan and be integrated with the modules assembled in Japan into the vehicle. The integrated vehicle will

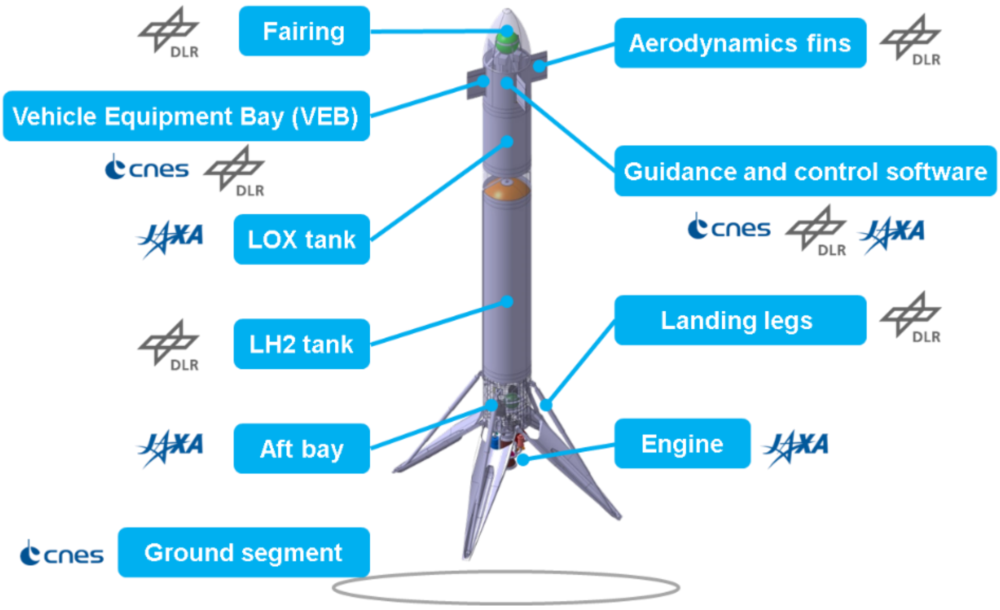

Fig. 3. Main elements and responsibilities.

undergo vehicle-level ground tests in JAXA Tsukuba Space Center. Subsequently, it will be conveyed to Noshiro Rocket Testing Center and be subjected to several static firing tests.

Upon completion of the tests in Japan, the vehicle will be transported to CSG. In CSG, tests combining the vehicle and the ground segment will be conducted before flights.

The flight campaign will proceed in a step-by-step approach to reduce risks. Four risk-reduction flights and a demonstration flight are considered for each of the two flight software products at the present moment.

The refinement of the development and test plan and the plan for maintenance, repair, and overhaul (MRO) operations after flights in CSG are ongoing among the three agencies.

6. Mission Profiles

Figure 4 shows an example of mission profiles. A downrange trajectory has been studied for the demonstration objectives. The vehicle will land on a platform on the sea. The three red parts of the trajectory in Fig. 4 correspond to powered phases

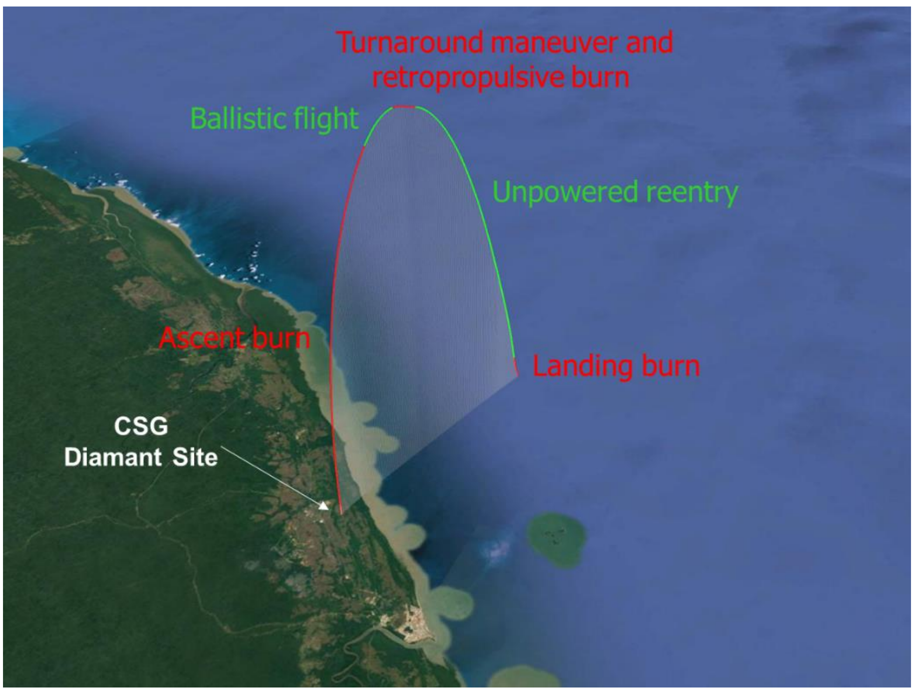

Fig. 4. An example of mission profiles

where the engine is turned on, while the two green parts unpowered phases. The flight sequence is similar to those carried out by future operational reusable first stages.

For risk-reduction flights where both downrange and altitude are limited as compared with demonstration flights, the vehicle will land on landing zones in the proximity of the Diamant launch site. MRO operations after flights will be performed in Vehicle Preparation Hall (VPH) at Diamant site in CSG.

7. Concluding Remarks

This paper has described an overview of the CALLISTO project with respect to mission requirements, project organization, development and test plan, vehicle, and mission profile. JAXA, CNES and DLR have jointly conducted the preliminary definition study of a scaled reusable VTVL demonstration vehicle to master key technologies for future reusable first stages. A joint preliminary design review (PDR) is scheduled within 2019 to complete the present joint activities and to move to the next project phase.

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