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Space Rider's inspection by a CoBot

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Abstract

The primary objectives of the Space Rider project is the definition and development of an affordable reusable European space transportation system to be launched by VEGA launcher and able to perform experimentation and demonstration of multiple missions in low Earth orbit.

As an answer to these objectives, Dassault Aviation proposed a list of various applications. Among them, the use of a space CoBot in order to inspect the Space Rider vehicle in orbit is foreseen.

The Space CoBot will look like a 6U CubeSat. It will be able to perform autonomous outside inspection of Space Rider, turning around it before returning in the Multi-Purpose Cargo Bay (MPCB).

1. Introduction

Dassault Aviation is a French high-tech company with more than 100 years of experience. It is the only group in the world to design, manufacture and support both combat aircraft and business jets. Dassault Aviation has been acting in space since 1962.

1.1 Dassault Aviation and Space Rider programme

The Intermediate eXperimental Vehicle (IXV) program was launched in 2008 by European Space Agency (ESA), involving mainly Italy, Spain, Switzerland and France and where Dassault Aviation was in charge of the shape and related aerothermodynamics studies of the re-entry module. The vehicle successful flight occurred in February 2015, paving the way for the Space Rider program continuation from 2016.

ESA's Space Rider aims to provide Europe with an affordable, independent, reusable end-to-end space transportation system integrated with Vega C, for routine access and return from low Earth orbit. It is composed by two modules:

- The AVUM Orbital Module (AOM), a modified version of the Vega C Upper Stage,
- The Re-entry Module (RM), a modified version of the IXV demonstrator integrating a MPCB equipped with standardized but customizable interfaces for the payloads, performing ground landing in European territory, being reusable following refurbishment after each flight.

It will provide a space laboratory to transport payloads into space for a variety of applications, orbit altitudes and inclinations, for missions lasting up to two months or longer if needed. Among the multiple exploitation capabilities and potentials, the Space Rider missions will tackle:

- Free-flying applications, such as experiments in advanced microgravity environment,
- In-orbit demonstration and validation of technologies for exploration, orbital infrastructure servicing, Earth observation, Earth science, telecommunications…,
- In-orbit applications for Earth monitoring, satellites inspections, space debris removal…,

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- Surveillance applications, such as Earth disaster monitoring, satellites inspection.

After the payloads operations into space, Space Rider will deorbit with the payloads stowed in its cargo bay, and return to Earth to land on the ground. During re-entry, at speed around Mach 25, the vehicle will face extreme thermal conditions from the flux of plasma thanks to reusable thermal protection.

Space Rider mission and environment are described in [1].

In 2018, ESA announced an opportunity to fly Payloads on Space Rider Reusable Space Transportation System and requested for potential missions to which Dassault Aviation answered and proposed the following nine experiments:

1	ENVISAT observation	Detailed High Definition (HD) recording of ENVISAT spacecraft (S/C) complete external status, attitude and spins, Inertia/Mass/Centring (IMC), nearby debris …
2	ENVISAT simulated capture	Fly-by, attitude and spin alignments, contact, and potentially "capture" (without capability to deorbit the composite)
3	Space Arm demo	Deployment of an handling arm, secured to Space Rider System (SRS)
4	Space CoBot demo	Deployment of a CubeSat with two handling arms, turning around SRS and returning to cargo bay
5	Quantic telecom demo	Test of quantic telecom (not just cryptography) between two items in space, one staying in space the other one coming back to earth
6	Low cost Light-Fidelity (LI-FI) in-orbit validation (IOV)	Test of LI-FI connection between two items in space environment
7	Digital Pyro IOV	Aging of digital pyro devices in space environment
8	Thermal materials demo	Testing of resistance to re-entry conditions
9	Re-entry shape demo	Testing of subscale re-entry vehicle with local autonomous recording

Space CoBot demo was subject to further analysis, summarised in the present paper.

1.2 Dassault Aviation background

The use of CoBot fitted with Charge Coupled Device (CCD) cameras to inspect remote areas on civil aircraft is a standard maintenance practice. The current step is to inspect the whole aircraft, either civil or military. This allows automating a sequence of tasks, removing the risk of human errors. When associated with image post-processing and Artificial Intelligence (AI) technics –Deep Learning and Knowledge Big Lake-, this will allow a deeper knowledge of the actual status of the aircraft resulting in an adequate and optimized maintenance.

In 2018 with his partner well-established in civil aviation area, Dassault Aviation realized a series of tests on the Rafale military fighter allowing the company to master the issues linked with the use of such a system for the whole aircraft.

For the Space Rider, Dassault Aviation proposes to transpose this concept of maintenance CoBot into the space environment. Obviously, CCD cameras will not be the only sensor as the threats are not the same in the space, so additional sensors will be also used to allow a complete inspection of the Space Rider.

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Figure 1: Demonstration of Rafale aircraft inspection by a mini-drone [2]

2. Inspection of Space Rider vehicle by a CoBot

Debris in orbit is becoming a more and more worrying problem for satellites or vehicles staying in orbit during a long period. Every year, the International Space Station has to perform a few numbers of specific manoeuvres in order to avoid space debris. As Space Rider will perform several month long missions, encounters with debris have to be taken into account. An inspection of the vehicle at certain key moments of the mission is proposed through the use of a space CoBot.

2.1 Mission analysis

Four phases were identified:

- Waiting in the cargo bay: CoBot is fixed in its station. During the period preceding its task, the battery is put in charge,
- Exit from the cargo bay: CoBot is deployed outside the bay and placed at a given position, about 10 meters away from the Space rider,
- Inspection: it consists in taking pictures of the vehicle from different points of view. Two types of inspections are possible: the first one is a general inspection. According to a predefined path, the CoBot will inspect the whole Space Rider. If necessary after analysis of the results of this checking, an inspection dedicated to a specific zone is possible.
- Return to the cargo bay: at the end of the inspection, the CoBot goes back to its station.

Several inspections are able to be made during Space Rider's two-to-six month mission, the total duration being limited by the amount of gas using for propulsion. At the moment, six hours are taken into account. Battery is planned for two hour inspection duration.

Figure 2: Illustration of CoBot use

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From an operational point of view, a general inspection mission should be planned a few days before the re-entry of Space Rider to check the state of the vehicle. Management of gas for propulsion has to make a specific inspection possible after the general one.

As the Space Rider is launched under the Vega fairing, the first general inspection has not to be planned during the beginning of its mission. For example, it could be performed after the end of the microgravity operational mode [3].
Pictures are sent to Space Rider control centre and analyses. A new inspection related to a specific zone of the vehicle may be asked if needed.

If a non-acceptable damage is identified, a temporary fixing for one safe re-entry should be made possible in next evolution of the CoBot. Currently envisaged cure, to be confirmed by further studies, would be deposit of a patch of thermal protection above the damage.

2.2 Necessary technologies and equipment

The necessary elements of the CoBot are defined by its mission:

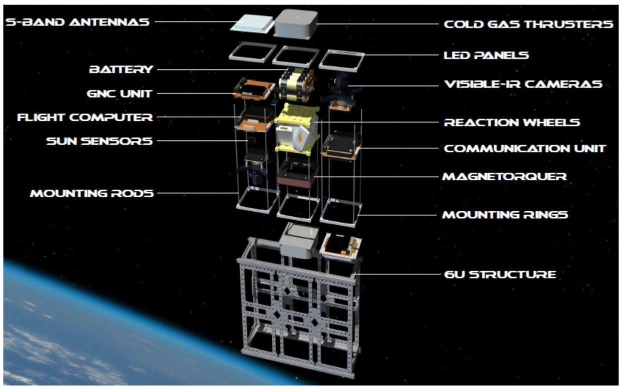
- A camera, able to deliver 3 megapixel pictures, with wide angle lens. It has its proper storage memory and Light-Emitting Diode (LED) equipment,
- Communications: to send pictures and to receive flight plans,
- Guidance, navigation and control system, enabling the CoBot to exit from the cargo bay, to fly the planned path and to come back,
- Propulsion: the considered system works with cold gas. It enables the CoBot to stabilize outside the cargo bay and to move around Space Rider,
- On board computer,
- Electrical power: delivered by a high-capacity lithium ion battery pack with a heater.

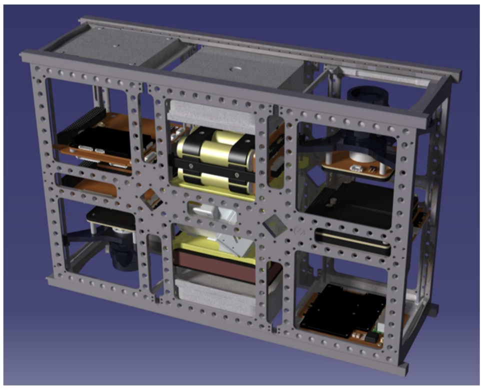
The different elements are off-the-shelf components, used for Cubesats. Two cameras and two cold gas thrusters are considered.

Future elements for thermal protection fixing function could later be handling arms, punch, patch, injection needle …

2.3 Architecture of the CoBot

Equipment are arranged in the structure so that moment of inertia on each axis is minimised and centre of gravity is superposed on geometric centre. The dimensions are 340 mm length, 225.8 mm high and 100 mm thickness. It weighs 4.84 kg.
A multi-layer insulation (MLI) coating covers the CoBot so that it will stay in a temperature range compatible with operating conditions for sensors and equipment.





Figures 3 and 4: Equipment in CoBot – Exploded view on left

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2.3 CoBox

The docking station enables to store the CoBot when unused, to charge it before an inspection and to eject it. It has a rectangular base 300 x 600 m and is 300 mm high. This box contains a funnel shape to guide the approach of CoBot and it opens and closes thanks to two shutters activated by step motors. When they are off, flaps are held in position thanks to electromagnetic brakes. At the bottom of the docking station, a socket is mounted on springs. They are compressed when the CoBot is in its CoBox and are released at the beginning of the inspection, in order to eject the CoBot outside the Space Rider.

Regarding storage, the important thing is to ensure that the CoBot is well stuck in the CoBox and cannot move. The shutters of the CoBox close in order to properly stall the CoBot.
To charge the CoBot on the electrical network of Space Rider, two retractable and symmetrical male pins are located at the bottom of the CoBox. Once the CoBot is docked and properly fixed, one of the pins is directly plug in its battery connection.

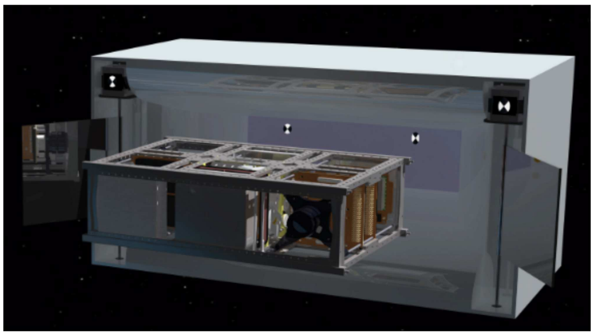

Figure 4: CoBot and its station called “CoBox”

2.4 Inspection paths

The inspection of the Space Rider may be either global or specific as mentioned in paragraph 2.1 Mission analysis.

To exit from the cargo bay leads the CoBot to perform a vertical ascent up to 10 meters far from Space Rider. This distance allows the Space Rider to be completely in the field of view of the camera and the CoBot to be high enough to avoid colliding with the vehicle.
For the global inspection, as travelling around Space Rider could be very gas consuming, the best solution is that Space Rider will perform a back flip manoeuvre -complete 360 degree rotation-, as the Space Shuttle realized before docking to International Space Station (ISS), after Columbia accident. Rotation rate has to be defined in order to have good quality pictures and complete coverage of the vehicle. This solution may be used when no particular experiment is on duty.
If a global inspection is required during specific tasks, trajectories not involving motion of the Space Rider and remaining affordable for the CoBot could be performed. Referring to the article “Mission Design and Trajectory Analysis for Inspection of a Host Spacecraft by a Microsatellite” [4], consumption of gas is minimized thanks to the relative movements between the CoBot and the Space Rider. These trajectories derive from the solution of so-called Clohessy-Wiltshire equations. They are different in nature (elliptical, circular, spiral ...), with the possibility of making transitions from one type to another. In addition, they allow for global inspections as well as local. To simplify the mission, while respecting the constraints and by reducing the gas consumption as well as the duration of the output, the elliptical trajectory 2x1 off plan seems to be an effective solution.
To return to the cargo bay, the CoBot will achieve a downward vertical movement.

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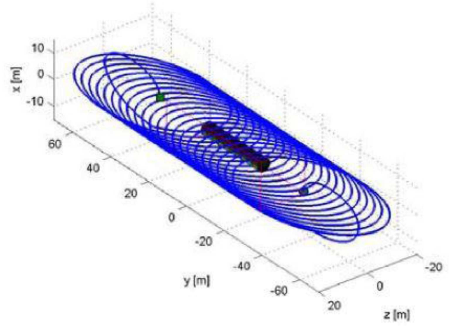

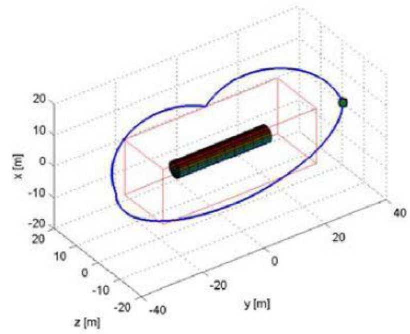

Figure 5: Examples of trajectories defined according to Clohessy-Wiltshire equations

Exit from and return to cargo bay is similar for the local inspection.
In the case a particular area of the Space Rider has to be scrutinized, the path will consist in taking photographs of this specific area of the outer surface of the Space Rider. To ease this task, Space Rider entire surface have to be divided into different zones identified and marked by markers that the CoBot is able to detect and identify. The more areas exist, the better the accuracy of the inspection is improved.

Simulation of trajectories has to be performed to check gas consumption and to test navigation and attitude commands and controls.

3. Conclusion

Space Rider is the first reusable European vehicle and it opens a new sector of activities. To become a third viable element of the European strategy after launchers and satellites, safety of the vehicle has to be dealt with, especially toward debris. The proposed CoBot is a solution coming from aeronautical Dassault Aviation background. It will be a first step for orbital inspection and could be further extended to orbital cure and manned vehicle.

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