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Feasibility analysis of a CubeSat mission for space rider observation and docking

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Abstract. In the last few years the number of orbiting satellites has increased exponentially, in particular due to the development of the New Space Economy. Even if this phenomenon makes the space more accessible, bringing a great contribution to the scientific, economic and technological fields, on the other hand it contributes to the overpopulation of the space background. Therefore, it is necessary to develop new techniques to manage the space environment, such as in orbit servicing, which is a procedure that aims to refuel and repair satellites to extend their operational life. A first step to reach this goal is to inspect closely the object of interest to study its features. In this framework, the Space Rider Observer Cube (SROC) mission is being developed. SROC is a payload that will be deployed by Space Rider, an uncrewed and reusable robotic spacecraft designed by ESA. SROC is a 12U CubeSat, whose goal is to carry out inspection manoeuvres around the mothership, then re-enter on board using a safe docking system to come back to Earth. The feasibility of a mission similar to SROC has been simulated during a university class, starting from the definition of the system requirements with particular focus on the analysis of the payloads and subsystems, to ensure the achievement of the mission goals. In particular, the CubeSat is equipped with an optical instrument to capture high resolution images of Space Rider surface and a docking mechanism. Then the design of the orbit and the simulation of the effects of the space environment on the CubeSat have been studied using GMAT, SYSTEMA, MATLAB and other numerical tools. The results of the study are useful for future missions, aiming to inspect orbiting objects, such as operative satellites for in orbit servicing, space debris and dead satellites to study their geometries and plan their removal.

Introduction

As the number of orbiting objects around Earth is constantly rising, it is necessary to develop new strategies to manage the space environment. For this purpose, it's crucial to study the space objects in-situ with a close observation for future in orbit-servicing missions that will allow to extend the operative life of functional satellites. Examples of these missions are: Seeker, a 3U CubeSat used to complete autonomous mocking inspections [1] and AeroCube-10, a 1.5U CubeSat created to demonstrate precision satellite-to-satellite pointing [2]. However the number of space missions involving CubeSats meant to inspect other satellites remains low. The aim of this work is to contribute to this field studying a CubeSat inspired by SROC (Space Rider Observer Cube), a future mission designed by ESA in conjunction with Politecnico di Torino and Tyvak International, that aims to carry on inspections and docking manoeuvres with its mothership Space

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Rider (SR), a reusable robotic spacecraft. In fact, SROC will reach its operative orbit inside Space Rider cargo bay and then will be deployed by it [3,4].

This project has been developed during a university class, and it started from the definition of the system requirements, followed by the selection of components and sizing of the subsystems, leading to the preliminary design of the system (Fig. 1).

Requirements and preliminary definition

Starting from the mission objectives of performing safe inspection and docking manoeuvres and transposing them into mission requirements, all the subsystems with their performance level have been defined. Afterwards, the design and operational requirements have been taken into account to reach a first iteration of requirements. Since the CubeSat is inspired by SROC, it has some similarities that have been included in the requirements such as its 12U structure, an imaging payload and a docking payload. It was established that Space Rider model orbit should be a 600 km dawn dusk 6 a.m. Sun Synchronous Orbit.

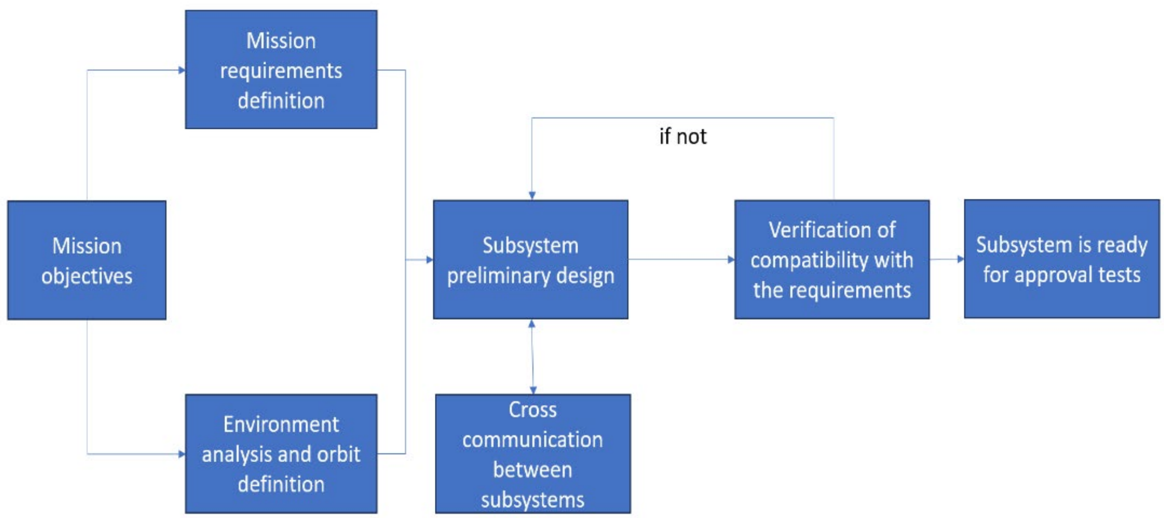

Fig. 1: Work procedure

Mission phases

The initial date of departure of the CubeSat from the mothership is set to be June 21, 2024, chosen to reduce the umbra periods and increase the electric power collected by the solar panels. Three reference frames have been designed for the simulations implemented in GMAT and MATLAB: the Earth inertial frame MJ2000Eq to define the mothership motion around the planet (Fig. 2a) [5]; radial in-track cross-track (RIC) centred in the mothership (Fig. 2a) and the CubeSat body frame to describe its relative orbit (Fig. 2b).

The motion of the CubeSat around the mothership is described by a Walking Safety Ellipse (WSE), chosen to be a safe orbit for both satellites. [6]

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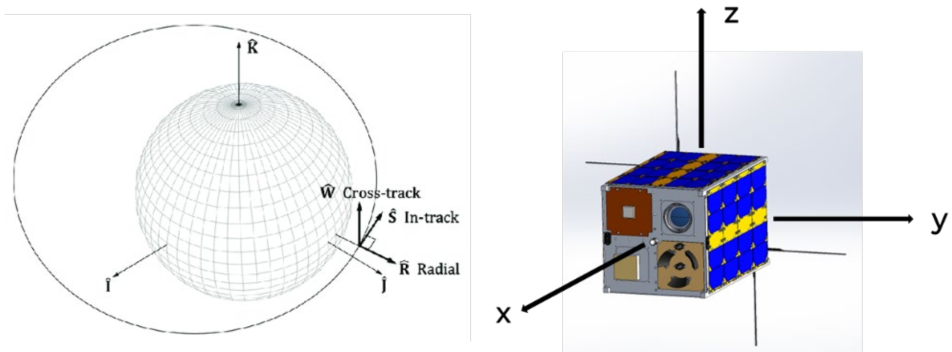

Fig. 2: a. MJ2000EQ and RIC frame system; b. Body system

The mission is designed to last 25 days, and its operative life can be divided in six phases:
1. Departure from Space Rider model (five hours): the CubeSat separates from the mothership and prepares for the first manoeuvre;
2. WSE entering phase (five hours): the CubeSat achieves the RIC coordinates to enter the WSE;
3. Inspection on a WSE orbital keeping: the CubeSat moves forward in the WSE for two days, then performs the orbital keeping manoeuvres to return to the initial conditions to repeat the inspection. This cycle is performed eleven times, to take pictures of the entire surface of the satellite in different conditions;
4. WSE departure: the CubeSat is brought to a stationary point, 100 m far from the mothership;
5. Hold Point approach (five hours): the CubeSat reaches a hold point at 50 m from SR model;
6. Rendezvous phase: the CubeSat reaches a 2 m distance from the mothership through a bang-bang technique.

CubeSat design

The CubeSat has the standard dimensions of a typical 12U CubeSat with a mass of 16kg. The skeleton of the external structure is made of Aluminium 6061, closed by graphene panels. Two other panels are added to the internal structure to create different zones inside the satellite and facilitate the storing of the components.

The satellite has two payloads: a camera (CMOS sensor and optical lens) that fits 1U and a partially external docking mechanism, whose dimensions are 1U. The camera is protected by a "Zerodur" layer. The images are taken and then transferred to the On-Board Computer (OBC) to be processed and then sent to Earth by the Telemetry and Tracking Control subsystem (TTC) antennas. The TTC communicates with ground stations using UHF band, through which the satellite also transmits telemetry data and receives commands.

The CubeSat is equipped with an Attitude Determination and Control Subsystem (ADCS) based on an Inertial Platform (Inertial Measurement Unit, IMU), navigation system GNSS, a magnetometer and multiple sun sensors to determine the configuration of the CubeSat around the Space Rider model. In addition, three reaction wheels are used for disturbances control and one for redundancy, together with three magnetorquers for their desaturation, while a momentum wheel is necessary to maintain the pointing towards SR during the inspection on the WSE.

The electric power, essential to all subsystems, is guaranteed by body mounted solar panels, positioned on the 6U faces and on the 4U face opposed to the camera lens, and a Li-Ion battery that comes into play when the energy provided by the panels is not sufficient. These components form the Electric Power Subsystem (EPS). The surface of the solar panels is covered with 125μm "Kapton". The thickness has been chosen to resist erosion due to the atomic oxygen.

The environment analysis (external and internal) has been realised with MATLAB, SPENVIS and Systema, and it suggested that a passive Thermal Control Subsystem (TCS) is sufficient to guarantee the maintenance of the operative temperature for individual components: for that purpose, the ADCS components have been covered with a Multi-Layer Insulation (MLI) material. Furthermore, it is not necessary to equip the satellite with a device for dissipating the internal thermal energy, i.e. a radiator.

The propulsive system consists in three cold gas B1 thrusters, fuelled by N2O propellant (nitrogen peroxide). This propellant is self-pressurising and has a good thermal control in space. This technology has been chosen because it presents a low power consumption, low mass and can perform every requested manoeuvre during the mission.

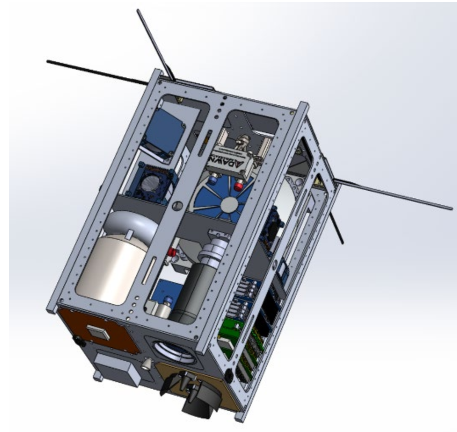

Fig. 3: CubeSat CAD without solar panels

In the end, the CubeSat is provided with a drag sail that will be used in case of docking failure to guarantee the compliance with the Space Debris Mitigation Guidelines.

Discussion and conclusions

During this study, some issues related to the CubeSat design arose. The resolution of the camera has been one of the most challenging aspects, because it is not only related to the pictures quality level, but it is also fundamental for the choice of a technology that can fit in the CubeSat. Moreover, the communication frequency band has been discussed, starting from a S-band communication to send images and a UHF band for the telemetry and command data. Due to power consumption issues, the UHF band has been chosen. In fact, the body mounted configuration is not able to provide the electric power necessary to guarantee an S-band communication. This led to the definition of two configurations for the EPS: the first one consisting of Sun tracking deployable solar panels, the second using the same structure without the Sun tracking mechanism. Both alternatives proved to be unsuitable as one of the mission objectives is to provide a way to dock safely with the mothership.

This paper showed the feasibility of the mission, giving results that will be useful for future missions developed with the goal of making in orbit servicing a reality. Further details on this work will be provided in a future extended paper.

References

[1] Brian Banker, Scott Askew "Seeker 1.0: Prototype Robotic Free Flying Inspector Mission Overview" NASA Johnson Space Center 2019

[2] Gangestad, Joseph W., Catherine C. Venturini, David Hinkley and Garrett Kinum. "A Sat-to-Sat Inspection Demonstration with the AeroCube-10 1.5U CubeSats." (2021).

[3]https://www.asi.it/en/technologies-and-engineering/micro-and-nanosatellites/esa-gstp-fly-program/sroc/ (accessed: June 2023)

[4]https://www.esa.int/Enabling_Support/Space_Transportation/Space_Rider_overview (accessed: June 2023)

[5] Kim, Eunhyouek & Han, Seungyeop & Sayegh, Amer. (2019). Sensitivity of the Gravity Model and Orbital Frame for On-board Real-Time Orbit Determination: Operational Results of GPS-12 GPS Receiver. Remote Sensing. 11. 1542. https://doi.org/10.3390/rs11131542

[6] Gaylor, David & Barbee, Brent. (2007). Algorithms for safe spacecraft proximity operations. Advances in the Astronautical Sciences. 127. 133-152.