Concept and feasibility analysis of the Alba CubeSat mission

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Keywords: CubeSat; Feasibility Analysis, Debris, Fly Your Satellite! Design Booster

Abstract. Alba CubeSat is a 2U CubeSat which is being developed by a student team at the University of Padova. The Alba project aims to design, build, test, launch, and operate University of Padova's first student CubeSat, featuring four different payloads that aim to satisfy four independent objectives. The first goal is to collect data regarding the debris environment in LEO, the second goal is the study of the satellite vibrations, the third one is about CubeSat attitude determination through laser ranging technology and the fourth goal concerns satellite laser and quantum communication. The Alba CubeSat mission has been selected by ESA to join the Fly Your Satellite! Design Booster programme in December 2022. This paper presents the feasibility study of the Alba CubeSat mission reproduced in the framework of the "Space Systems Laboratory" class of M.Sc. in Aerospace Engineering at the University of Padova. In the beginning, a mission requirements definition was conducted. After that, the mission feasibility was considered, with preliminary requirements verification to assess the ability of the spacecraft to survive the space environment, including compliance with Debris Mitigation Guidelines, ground station visibility and minimum operative lifetime evaluation. The Alba mission sets a base for a better understanding of the space environment and its interaction with nanosatellites, and an improvement of the accuracy of debris models. Furthermore, this paper, describing the educational experience and the results achieved, will provide a useful example for future students' studies on CubeSat mission design.

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Introduction

One of the most common trends in the space sector is the evolution of CubeSats, micro satellites measuring just a few tens of centimeters in size. Their strength is not just the small dimensions and weight that guarantee a reduction of power consumption and costs, a CubeSat is also the perfect chance to sharpen the students' abilities and knowledge of the space industry. For that purpose, an accurate and comprehensive research of a CubeSat mission has been done by students, with a special focus on the requirements definition, starting with mission objectives. This activity has given the opportunity to face and address the issues and challenges of a space mission design. In the present work an alternative design of the 2U CubeSat mission of the student team Alba CubeSat of the University of Padova [1] is presented.

Students' work was aimed to define the requirements, based on which the commercial off-the-shelf (COTS) components have been selected for a preliminary design, while maintaining the original design of the four payloads. In addition, the students' team has identified and evaluated the risks and the success criteria, and they have carried out a wide variety of simulations in order to perform a complete feasibility analysis.

Mission overview

Alba CubeSat is a project that aims to design, build, test, launch, and operate University of Padova's first student-built 2U CubeSat, which features four distinct payloads that seek to achieve four independent objectives. In particular, the derived mission requirements are:

1. to collect in-situ measurements of the sub-mm space debris environment in LEO;
2. to study the micro-vibration environment on the satellite throughout different mission phases;
3. to do orbit and attitude determination through laser ranging;
4. to investigate alternative systems for possible Satellite Quantum Communication applications on nanosatellites using active retro-reflectors.

Starting from these, the system requirements were defined according to the process shown in Figure 1. The identification of requirements is a milestone that is the basis of any design activity. In order to define the requirements, assumptions were made, such as the altitude and type of operative orbit, the launch vehicle that will carry the CubeSat and the launch date. The study of the micro-vibration sensor and active retro-reflectors is beyond the scope of this paper.

For every requirement identified, one or more of these verification methods were assigned: analysis, test, review of design and inspection. Throughout the analysis, each requirement was subjected to review, update and tailoring as the mission development progressed and different needs or constraints emerged.

Another critical activity was the identification of risks and success criteria. The students compiled a risk register, in which the level of risk was evaluated and mitigation actions were proposed. Since this is a student-designed CubeSat project, the majority of the success criteria were linked to an educational purpose.

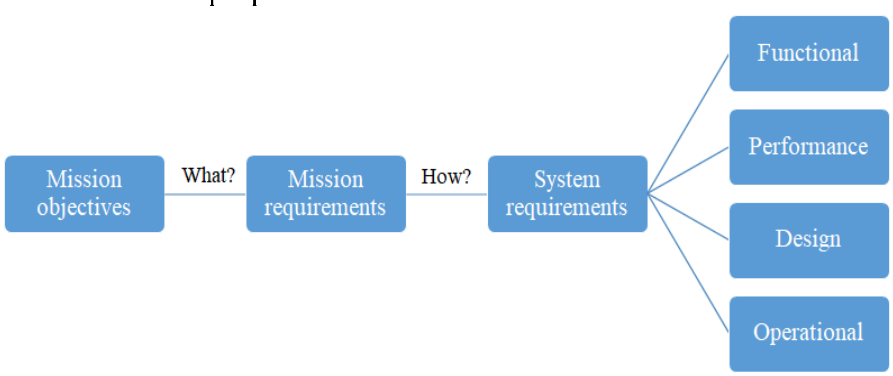

Figure 1: Logical scheme followed to identify requirements

Preliminary Analyses

An analysis of the possible target orbits has been performed considering the European Code of Conduct for space debris mitigation and the orbits commonly reached by other missions. A 500 km Sun-Synchronous Orbit (SSO) has been selected as the baseline for the mission. In order to be compatible with as many launches as possible, the LTAN has not been fixed. Therefore, the two extreme cases have been considered in the analyses, namely a worst hot case (WHC) scenario with an LTAN of 6AM (Dawn/Dusk), and a worst cold case (WCC) with an LTAN of 12AM (Noon/Midnight). The launch date has been assumed to be 30/03/2027 and the eccentricity of the orbit is 0.001.

With the chosen design (shown in the following section) mass budget and atmospheric reentry comply with ESA guidelines [2][3]. The thermal and power budgets have been calculated considering two extreme cases for on-board activities. At this stage, four operational modes have been defined: safe, idle, communication and payload. The two worst cases scenarios are representative of a safe mode for the minimum power consumption, and a communication mode for the maximum. Ground station visibility has been taken into account for link and data budget.

Environmental analyses have been performed to ensure component compatibility with thermal ranges, radiation and atomic oxygen interactions. Systema, an Airbus software, has been used for thermal and radiation analyses. The radiation analysis shows the accumulated radiation dose over the one-year operational lifespan (Figure 2). The thermal analyses show that the internal components reached a maximum temperature of 45 °C and a minimum of 39 °C in the WHC (Figure 3). In the WCC scenario, internal temperature ranges from -10 °C to 20 °C.

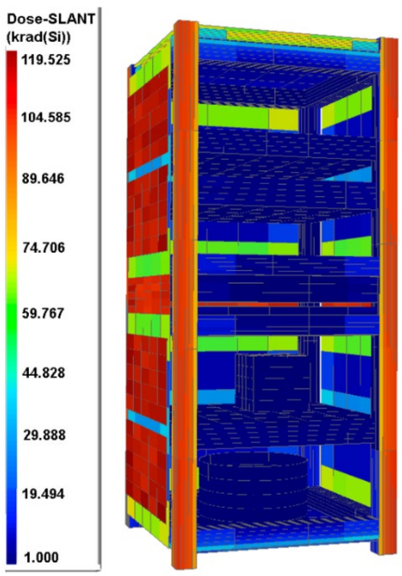

Figure 2: One-year cumulative radiation

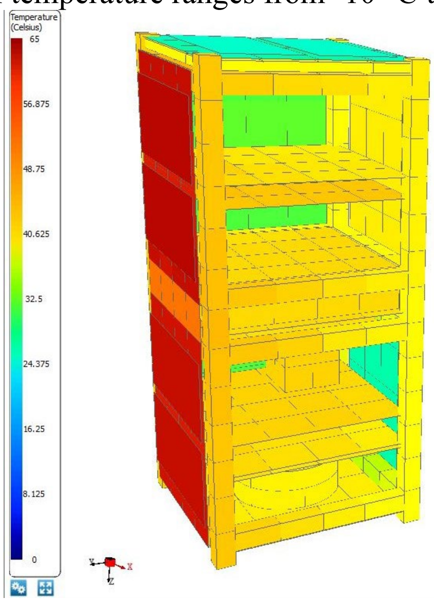

Figure 3: Component's temperature WHC

Subsystems and components selection

Component selection comes from the necessity to meet the requirements and system-level compatibility. After preliminary analyses, the following design choices have been made (Figure 4). Except the impact sensor, micro-vibration sensor and active retro-reflectors which are in-house developed, the other components are all COTS.

1. The four payloads are: the impact sensor which is a new system based on the technology demonstrator DRAGONS [4]; the laser ranging payload is composed by 6 CCRs with a 12.7 mm diameter; the micro-vibration sensor and the active retro-reflectors which are considered as black boxes with known specifications.
2. The 2U structure is made of an aluminum alloy (Al 6061) and is qualified according to ECSS-E-ST-10-03.
3. The ADCS is able to meet the three-axis stabilization pointing accuracy needed by the payloads (± 20° for each axis).
4. The power system includes: a 43 Wh battery pack and seven 1U solar panels.
5. Thermal management is based on passive conduction and radiation except for the battery pack which is equipped with a heater.
6. The OBC has been designed for space applications with limited resources. It fulfills the processing power, memory capacity, radiation tolerance and system-compatibility requirements.

7. The communication system comprehends a transceiver and an antenna. It is the most power-consuming subsystem during transmission, with a power consumption up to 3.3 W and an output power of 1 W.

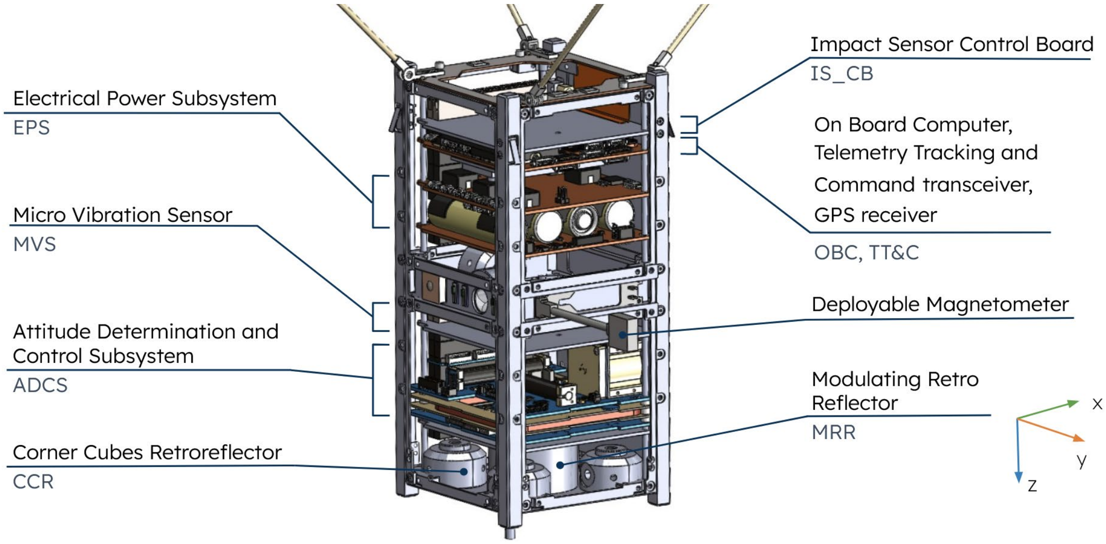

Figure 4: Internal components, solar panels have been removed

Conclusions

The successful development of this work involved several key tasks, including identifying requirements and their corresponding verification methods, identifying risks and find mitigation actions, designing and studying the functionality of two payloads (laser ranging and impact sensor), selecting appropriate commercial off-the-shelf (COTS) components for the subsystems, and conducting analyses to verify the specified requirements.

One of the critical points identified was the enclosure of all the components in a 2U, in particular the CCRs. Therefore, it is to be considered the development of a homemade structure for the CCRs to address this issue. Moreover, the power budget analysis revealed a potential insufficiency in power generation by the solar panels during the worst-case scenario (noon-midnight orbit). However, it is important to note that power consumption was likely overestimated.

The present work has contributed to enhancing students' understanding of how to conduct a feasibility study for a space mission. It also can serve as a useful reference, assisting anyone who is embarking on their first mission feasibility study.

References

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