Development of a multi-payload 2U CubeSat: the Alba project

Federico Basana[1], *Alexandru Andrei Avram* [2], *Francesco Fontanot*[2], *Luca Lion*[3], *Alessandro Francesconi*[2]

Abstract

Alba CubeSat UniPD is a student team of University of Padova with the aim to participate to the ESA Fly Your Satellite! (FYS!) programme and to launch for the first time at University of Padova a CubeSat made by students.

The proposed mission has three independent objectives: (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 precise orbit determination through laser ranging and evaluate procedures for fast satellite Pointing, Acquisition and Tracking (PAT) from ground. The proposed technological experiments aim to obtain data that will enrich the current knowledge of the space environment and will provide precious information useful for the further development of some research projects currently performed at University of Padova.

In order to reach the objectives, in these years the activities of the teams aimed to develop a 2U CubeSat equipped with three payloads. The first payload is an impact sensor that will be placed on one of the outer faces of the satellite and will be able to count the number of debris impacting the spacecraft thus being able to measure the energy/momentum transferred to the satellite. The second one is a Commercial Off The Shelf (COTS) sensor that measures the micro-vibrations experienced by payloads in a CubeSat in different mission phases. The third one consists in a number of COTS Corner Cube Retroreflectors that will be placed onboard the satellite. Thanks to this, Satellite Laser Ranging (SLR) will be done to collect data on the satellite range and range rate using a facility currently under development at University.

This paper presents the mission objectives and motivations. In addition, the mission phases and the preliminary design of the CubeSat reached during the activities of the project are shown. Particular attention is given to the payloads which are the most challenging aspect of this project.

Keywords

CubeSat, Impact sensor, Micro-vibrations, Laser Ranging

[1] Corresponding author: Centre of Studies and Activities for Space “Giuseppe Colombo” (CISAS), University of Padova, via Venezia, 15, 35131 Padova, Italy

[2] Department of Industrial Engineering, University of Padova, via Venezia, 1, 35131 Padova, Italy

[3] Centre of Studies and Activities for Space “Giuseppe Colombo” (CISAS), University of Padova, via Venezia, 15, 35131 Padova, Italy

Acronyms/Abbreviations

ADCS	*Attitude Determination and Control Subsystem*
CCR	*Corner Cube Reflector*
COTS	*Components Off The Shelf*
EPS	*Electric Power Subsystem*
FOV	*Field Of View*
FYS!	*Fly Your Satellite!*
GNSS	*Global Navigation Satellite System*
LEO	*Low Earth Orbit*
LEOP	*Launch and Early Orbit Phase*
OBC	*On-Board Computer*
PAT	*Pointing, Acquisition and Tracking*
POD	*Precise Orbit Determination*
SLR	*Satellite Laser Ranging*
TCS	*Thermal Control Subsystem*
TT&C	*Telemetry, Tracking and Control*

1. Introduction

In the last decade, the space industry has increased its interest in the development of small spacecraft mission based on the CubeSat standard. The possibility to employ readily available and inexpensive Components Off The Shelf (COTS) has the effect of decreasing the system cost and complexity in comparison to traditional satellites [1].

CubeSats were initially envisioned as educational or technology demonstration platforms that could be developed and launched in a short amount of time [2]. However, in the recent years more advanced CubeSat missions have been developed and launched such as: SunStorm, which aims to measure X-Ray fluxes [3], and RadCube, which has the objective to measure in-situ the space radiation and magnetic field environment [4].

The activity of Alba CubeSat takes place in this framework. Alba CubeSat UniPD is a student team from University of Padova, which aims to develop and launch a 2U CubeSat by participating to the ESA Fly Your Satellite! (FYS!) project. The objective is to obtain data that will enrich the current knowledge of the space environment and will provide precious information useful for the further development of some research projects currently performed at our University. These projects are in the fields of small satellites technologies, with focus on (1) space debris, (2) highly-stable pointing mechanisms, and (3) Pointing, Acquisition and Tracking (PAT) of small satellites with laser payloads.

2. Mission Objectives

The proposed mission has three objectives: (1) collect in-situ measures of the sub-mm space debris environment, (2) study the micro-vibration environment on the satellite and (3) do orbit determination through laser ranging. These objectives and their motivations are presented in the following sections.

2.1. Collect in-situ measure of sub-mm space debris environment

The small debris population cannot be observed from ground and available models require validation through in-situ measurements [5,6]. To this aim, several missions and payloads have been proposed, e.g. the ESA "Debris inOrbit Evaluator" (DEBIE I, DEBIE II) [7], the NASA "Space Debris Sensor" onboard the ISS [8], the "in-situ micro-debris measurement system" from JAXA [6], the piezoelectric sensor developed by University of Texas at Austin onboard the Armadillo CubeSat [9], and the solar panel-based impact detector SOLID [10]. To reach this first objective the team plans to develop an impact sensor that will be placed on the outer faces of the satellite, those not covered by solar panels.

2.2. Measure micro-vibrations on board

Micro-vibrations on spacecraft represent an issue for payloads requiring high pointing accuracy and/or stability over time [11], and they might represent a particular concern for CubeSats and small satellites that normally are not equipped with very-high performance attitude control subsystems. Furthermore, simulating real orbital disturbances is difficult on ground [12, 13], and hence collecting reliable measures of the possible vibrations spectra in realistic operational scenarios is a significant research activity. Micro-vibrations in space have been measured in few missions such as SAMS-II and AMAMS by NASA [15, 16]. However, to our best knowledge there is a lack of information about micro-vibrations on small satellites and there is also the need of correlating such vibrations with typical mission events (e.g. activation of actuators, thermal cycling, debris impacts, etc.) [17]. This will help to improve the pointing accuracy and stability of future high-performance payloads for small satellites. To reach this second objective, we aim to measure vibrations with COTS sensors, such as accelerometers, and correlate the measurements with scheduled as well as unpredicted mission events.

2.3. Orbit determination through laser ranging

Satellite Laser Ranging (SLR) has been used in many important scientific missions for precision orbit determination (e.g. GOCE [18] and Galileo [19]). Several examples of CubeSat using this technique can be found such as Nice Cube [20], BeoCube [21] and CUBETH [22].

In order to reach this objective, a number of COTS Corner Cube Retroreflectors (CCR) will be placed onboard the satellite and SLR will be done to collect data on the satellite range and range rate. To this aim, we will consider the opportunity of using a new facility under development at our university for testing laser communication with LEO satellites. This facility is based on a telescope with automated azimuth/elevation control, a beacon laser and a receiver section with active focusing of the laser spot. Alba CubeSat satellite will be used as a real target for testing several PAT procedures.

3. Mission description

Three main mission phases have been foreseen at the current project design state. These are the followings:

1. Launch and Early Orbit Phase (LEOP)
2. Operations
3. Disposal

The LEOP is characterized by three different modes: (1) launch mode, (2) detumble mode and (3) coarse Nadir Pointing mode. In launch mode, all non-essential systems will be turned off, and the main objective is to remain alive until the satellite deployment. During the detumble mode all non-essential systems are still offline and the main objective is to reduce the rotational rate down to a certain threshold. This mode is accessed immediately after the deployment of the satellite and in the case of an emergency. A robust ADCS is used to accomplish this phase, with the aid of actuators and sensors like magneto-torquers and sun-sensors. The coarse Nadir Pointing mode constitutes the first actual operational mode. Here a low precision Nadir Pointing attitude is obtained, and the first link with mission control is established.

The operations phase is the core of the satellite schedule. Here all the subsystems and payloads are turned on. In the current design state, the sub-modes of the operations phase still not completely defined. Nevertheless, two modes have been already defined: (1) idle mode and (2) safe mode. The idle mode is activated if no operations are scheduled. The objectives of this mode are to maintain the satellite operative and keep the battery charged. In the current design a nadir pointing attitude is maintained for this mode, but a sun pointing attitude is still being considered. The safe mode is part of the constant monitoring of the satellite conditions, and it is activated whenever one alert condition is triggered. The alerts consist in non-nominal or unexpected events like:

- No ground contact for a certain amount of time;
- Off-nominal telemetry;
- Low battery voltage.

Once one of the alerts is triggered, the satellite, completely autonomously, runs a status check and assessed its condition. This mode is maintained until the satellite conditions are nominal again and a command is received from mission control.

The last planned mission phase is the disposal phase. This mode is activated once the satellite's expected lifetime is over. Once this phase is reached all switches are opened and the batteries are completely drained. The satellite follows a passivation procedure and loses any control or operative ability. This mode states the end of the mission and culminates with the satellite's passive de-orbit.

4. CubeSat design

The team is following the concurrent engineering method to reach the critical design of the CubeSat. The key features of the method are the constant and intensive communications between all members, and the spiral process of design which tries to reach the best solution. The concurrent approach has been studied in deep through the ESA hands-on experience called "CubeSat Concurrent Engineering Workshop".

The design process of the CubeSat has been driven by the payloads. The subsystems that compose the CubeSat were chosen and developed starting from the payloads requirements in terms of mass, volume, required power, required pointing accuracy and thermal range. Considering these requirements, the team decided to develop a 2U CubeSat platform. The functional description of the satellite is shown in Figure 1. The architecture of the satellite includes the needed subsystems to ensure the functionality of the payloads, i.e.:

1. TT&C: Telemetry, Tracking and Control System
2. EPS: Electric Power System
3. ADCS: Attitude Determination Control System
4. OBC: On-Board Computer
5. TCS: Thermal Control System

In addition, other critical aspects of the mission have to be taken into consideration, i.e. the mission analysis and the ground segment. In the following sections presents the payloads and the subsystems.

4.1. Payloads

The design philosophy that has been followed during the development of the CubeSat is to extensively use Commercial Off The Shelf (COTS) components. In this fashion, a robust and reliable design can be reached in a simpler way rather than implementing *ad hoc* components. The only exception to this philosophy is the space debris impact sensor which is being developed by the team.

The impact sensor combines several technologies to count the number and, possibly, to measure the energy/momentum transferred to the satellite by impacts with small debris (sub-mm size). The debris detector concept, which is currently under investigation, will be made by a multitude of thin, conductive strips (material: copper) which are made of a fine pitch (pitch: ~ 100 um) laid on a thin film of nonconductive material (thickness: ~ 12.5 um, material: polyimide). When a particle with an effective diameter larger than the strips collides against the sensor film and penetrates it, one or more stripes are severed and become nonconductive. Hence, an impact can be detected by monitoring the conductivity of the stripes. The sensor external area will be approximately 9 cm x 18 cm and will face the positive direction of the satellite velocity in order to maximize the probability of detection.

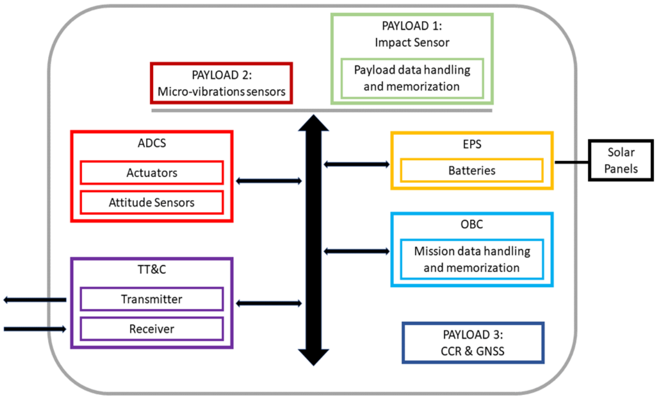

Figure 1: CubeSat functional description

For what concerns the measurements of the micro-vibrations on board the satellite, accurate COTS triaxial accelerometers will be used. The challenge related with this payload is to distinguish micro-vibrations from measurement noise. For this purpose, low-pass filters will be used in the measurement chain to decouple the measurement noise from micro-vibrations.

Precise Orbit Determination (POD) will be achieved through SLR. In fact, the CubeSat will host CCRs that will be placed on the face pointing nadir. For the time being an array of 5 CCRs of 12.7 mm in diameter has been implemented in a quatrefoil formation: one CCR in the middle with the face parallel with the satellite and the other four forming a cross with a vertical mounting angle of 50°. This design aims to improve the Field Of View (FOV) projection on the ground allowing greater visibility from the laser station and longer contact duration. The analysis of the data recovered by the returned signal will grant the possibility to determine the orbital parameters with greater precision than the standard navigation tools such as a GNSS receiver. The

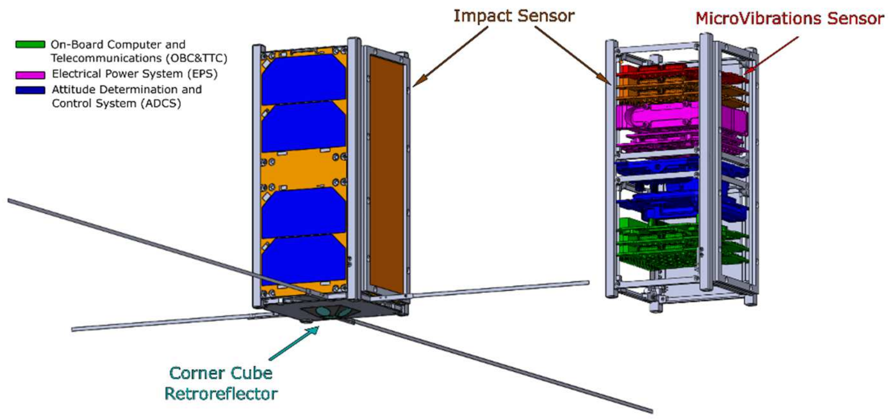

Figure 2: CubeSat preliminary design

design of the CCR array is still preliminary and could be modified in the future iterations.

4.2. Subsystems

For the time being the project is in the preliminary design review stages, hence the COTS components that have been considered for the subsystems may be changed in future.

The ADCS is the only subsystem responsible for the attitude determination and control of the satellite. The attitude is determined by means of sun sensors and magnetometers and maintained by means of reaction wheels and magnetorquers. In particular, 3 magnetorquers, along with the 3 magnetometers and the sun sensors, have to detumble the satellite during the detumble mode and compensate the environmental torques during the whole duration of the mission. The ADCS is intended to be placed as close as possible to the centre of mass of the satellite, to facilitate its operations. The power required by the system is generated by solar panels which are mounted on every face of the CubeSat with the exception of the faces that host the impact sensor and the CCRs respectively. The generated power is stored in batteries to guarantee the power to the system during eclipses. The data on board the satellite is managed by the OBC, which consists in a Pumpkin Motherboard Module 2 and a BeagleBone. The telemetry and data are transmitted to the ground segment by means of a UHF/VHF antenna and a VHF uplink/UHF downlink transceiver. Particular attention is given to the thermal control of the satellite: thermal sensors are placed in the proximity of the components which are more sensitive to thermal variations, i.e. batteries, payloads and on-board computer. In addition, specific thermal paths are designed in order to keep the satellite into the required thermal range. Figure 2 shows the preliminary design of the CubeSat obtained after several iterations in the preliminary design phase.

5. Conclusions

In this paper, the Alba CubeSat UniPD mission objectives are presented. The objectives are: (1) collect in-situ measures of the space debris environment, (2) study the micro-vibration environment on the satellite and (3) do orbit determination through laser ranging. Additionally, a brief description of the mission phases is provided. In order to reach the three mission objectives, three payloads have been developed: an impact sensor, a micro-vibration sensor and a structure of CCRs. Among these, only the impact sensor required to be developed *ad hoc* while the other two are COTS. Furthermore, a preliminary design of the 2U CubeSat is shown. In the future work, new iterations of the design will be executed in order to reach the optimal configuration of the system.

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