E.CUBE MISSION: THE ENVIRONMENTAL CUBESAT

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ABSTRACT

The e.Cube mission aims at contributing to the advancement of technologies and methodologies dedicated to space debris mitigation and remediation (1) to increase spacecraft autonomy in performing CAMs, (2) to support space debris modelling with in-orbit collected data about non-trackable fragment objects, (3) to characterise the atmosphere for more accurate re-entry predictions and the thermomechanical loads experienced by the spacecraft during re-entry. This paper presents the preliminary mission analysis, payload selection and system design for the mission.

INTRODUCTION

The space surrounding our planet is densely populated by an increasing number of space debris, whose number is expected to grow in the next decade due to in-orbit explosions, material deterioration, and in-orbit collisions. Space debris poses a threat to the current and future access to space. While debris objects larger than 5-10 cm can be tracked from Earth and need to be avoided through the execution of Collision Avoidance Manoeuvres (CAMs), smaller debris are not currently catalogued, therefore statistical distributions are used to quantify the collision risk in different orbital regions and to define mitigation guidelines through long-term evolution models. Moreover, while the design of End-Of-Life (EOL) disposal manoeuvres is desirable to mitigate the number of inoperative satellites, uncertainties related to our limited knowledge of the solar activity and its interaction with the atmosphere make accurate re-entry predictions a challenging task [1].

The e.Cube mission [2] aims at contributing to the advancement of technologies and methodologies dedicated to space debris mitigation and remediation (1) to increase spacecraft autonomy in performing CAMs, (2) to support space debris modelling with in-orbit collected data about non-trackable fragment objects, (3) to characterise the atmosphere for more accurate re-entry predictions and the thermomechanical loads experienced by the spacecraft during re-entry.

A 12U CubeSat will be deployed in Low Earth Orbit (LEO) where the operational phase will be dedicated to three experiments. During the first phase, the autonomous CAM experiment will be carried out, consisting of several in-flight CAM tests for simulated close approaches with a virtual debris. For each test, a sequence of virtual Conjunction Data Messages (CDM) will be generated on ground and uploaded to the spacecraft. The CAM payload processor will then decide if and how to perform the CAM making use of artificial intelligence. A particle detection device, exposed in the frontal side of the spacecraft, will collect over the time of one year the highest amount possible of sub-millimetre particles to be used to validate in-use statistical distributions of non-trackable objects. Finally, during the last phase of the mission an EOL manoeuvre will be implemented. During the re-entry phase an experiment through the re-entry data collector will characterise the thermosphere in the region below 200 km, through some in-situ measurements, in particular temperature and pressure.

The role of the e.Cube mission is to contribute to the advancement of technologies and methodologies dedicated to space debris mitigation and remediation. Three key areas have been identified: the development of autonomous CAM algorithms, the detection and measurement of untraceable space debris, and the characterisation of the upper atmosphere and of the satellite disposal mechanism. These three emerging areas are also the research pillars of the COMPASS project, funded by the European research Council at Politecnico di Milano [3]. The tools and techniques developed within this project have been already brought to their proof of concept thanks to projects funded by the European Space

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Agency (ESA) and the Italian Space Agency (ASI), however the status of the such algorithms is still at the preliminary operational software development. It is the aim of the e.Cube mission to develop operational software for Space flight and on-orbit experiments, and to send back to Earth relevant scientific data that will be used to validate long-term evolution models for space debris, re-entry prediction, and to improve autonomous CAM for the future Space Traffic Management (STM). The data and results of the e.Cube mission will be used to validate tools and techniques currently used within the space debris community: long-term evolution models for space debris, re-entry prediction, and to improve autonomous CAM for the future space traffic management. In line with the ideal of the e.Cube mission to contribute to the international discussion and cooperation on space debris mitigation, all the data and results of the on-board experiments will be freely shared with the whole debris community to be used for advancing the definition of space debris mitigation guidelines.

MISSION OBJECTIVES

The e.Cube mission aims at participating to the effort in Space Situational Awareness and Space Traffic Management, by providing a significant contribution to the development of key areas with the aim of ensuring a safer and more sustainable access to Space. In the rapidly evolving scenario of New Space activities, large constellations, and the increasing dependence of our daily life on Space, space agencies have identified the mitigation of space debris as one of the main goals for a sustainable development of space activities in the near future. The scientific objectives of the e.Cube mission, represented in Figure 1, address distinct but interlinked aspects of space sustainability, spanning the entire lifetime of any space mission. The first two objectives investigate the two sides of the same spectrum: the collision avoidance of traceable debris on one side and the improvement of the damage assessment from untraceable debris on the other. They will be explained in the next Sections.

Obj. 1 – CAM. Development, validation and testing of on-board algorithms for autonomous collision avoidance

To demonstrate autonomous collision avoidance capabilities during at least three relevant in-flight scenarios. This will be achieved by implementing the semi-analytical collision avoidance algorithms developed at PoliMi within the Manoeuvre Intelligence for Space Safety (MISS) software tool which couple the uncertainties in the environment model and orbit determination measurements [4]. Supervised artificial intelligence techniques will be employed for the planning and decision making in the operations for autonomous Collision Avoidance Manoeuvres (CAM). During the CAM in-flight experiment, synthetic conjunction data messages, simulating the possible collision threat with a debris, will be transmitted to the spacecraft and the CAM command module will autonomously decide, compute, and command the required manoeuvre to be performed [5]. An expected output of this objective is to advance the proposed CAM algorithms to autonomy level E4 E4 (goal commanding) according to "ECSS-E-ST-70-11C – Space segment operability".

Obj. 2 – DEBRIS. Characterisation of untraceable space debris objects to update and improve space debris environmental models (BRIS).

Obj. 2 will be fulfilled through the design of a particle detection device, which will characterise in-situ sub-millimetre level particles in Low Earth Orbit by sensing the frequency, mass, energy, and direction of debris particles. The Particle Detection Device (PDD) will be pointed in the velocity direction with 1-degree accuracy, to maximise the particle collection. To properly characterise the sub-millimetre debris (less than 1 mm) and meteoroids environment, the PDD shall collect at least 200 particles during the spacecraft operating life.

Obj. 3 – RE-ENTRY. Characterisation of the upper atmosphere for more accurate re-entry prediction and of the thermomechanical loads experienced by the spacecraft during re-entry.

Obj. 3 aims at reducing the model uncertainties on the post-mission disposal, and specifically on the re-entry phase, which arise due to the atmospheric modelling (especially the solar activity) and to the satellite demise and break-up process, a process for which little to no mission-related data is currently available. This objective will be achieved by arranging a distributed network of sensors inside the spacecraft that will measure the evolution of the acceleration, pressure, and temperature during the re-entry phase to record the mechanical and thermal loads suffered by the spacecraft. The experiment shall collect data in the region between 200 km and 100 km of altitude with a resolution of at least 10 km. The CubeSat shall transmit at least 125 kbit/s data to the ground until an altitude of 100 km.

Figure 1. Conceptual representation of the e.Cube objectives.

MISSION ANALYSIS

The selection of the mission and spacecraft architecture, the operational orbit, and the disposal strategy are fundamental aspects for the e.Cube mission. The selected configuration is a 12U CubeSat, which can best accommodate the three payloads required for the fulfilment of the objectives.

Given the distribution of space debris in the LEO region, the selection of the operational orbit directly influences Obj. 2. In fact, different orbital regions are characterised by different debris fluxes, which have a direct impact on the number of particles that can be analysed by the payload. Figure 2 shows the value of debris fluxes as a function of semimajor axis and inclination as computed with ESA MASTER 8 [6]. The regions with the highest fluxes correspond to Sun-Synchronous Orbits (SSO).

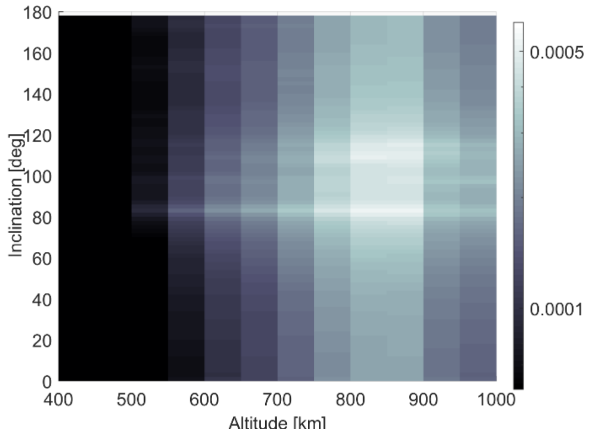

Figure 2. Debris fluxes for orbits between 400 km and 1000 km.

These orbits are the perfect candidates for a debris characterisation mission as they provide the possibility to collect a significant amount of data. Additionally, they have directional fluxes (concentrated in the front part of the spacecraft), which allow for a better detection of particles and design of the payload. Even if peak-flux can be experienced for orbits in the range 800-900 km, they would not be compliant, in case of failure of the on-board propulsion system, with the space debris mitigation regulations [7, 8], that require a decay of the satellite within 25 years (see Figure 3). For this reason, the operational orbit will be a SSO below 550 km of altitude to be compliant with the space debris mitigation regulations even without disposal manoeuvre, which is a strong requirement, given the objectives and background of the mission.

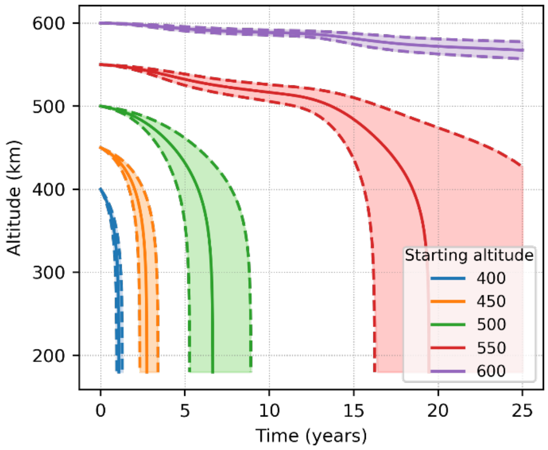

Figure 3. Natural decay time vs starting altitudes. Circular SSO orbits and solar flux uncertainties.

Table 1 summarises the estimated number of particles impacts for a one-year mission for orbits between 400 km and 800 km with a 12U CubeSat (cross-section of 0.2 x 0.2 m2). Particles with a diameter between 1 μm and 1 cm are considered in Table 1 as they are untraceable by current ground observation facilities [1]. Although a 500 km altitude orbit can detect less than half the total impacts with respect to an 800 km orbit, this amount is in line with the proposed target of 200 particles, while providing a safe EOL disposal considering a natural decay. Therefore, it is proposed an operational orbit of SSO type between 500 km and 550 km of altitude and a mission lifetime of at least 1 year, to reach the target of detected particles.

As Obj. 3 aims at characterising the re-entry of the spacecraft, it is important to design a proper disposal scenario. As the disposal phase is also part of the operational phase of the mission, it must be carried out within a timeframe that is compatible with the lifetime and reliability of CubeSat components. Therefore, a maximum disposal time of 6 months has been considered. The CubeSat will perform disposal manoeuvres to lower its perigee altitude and ensure the compliance with this requirement.

Table 1. Number of impacts per year on different operational orbits of SSO type.

Altitude [km]	Meteoroid impacts [#/year]	Debris impacts [#/year]	Total Impacts [#/year]
400	~ 122	~ 10	~ 132
500	~ 125	~ 70	~ 195
600	~ 126	~ 180	~ 306
800	~ 128	~ 320	~ 448

Another important aspect in view of the fulfilment of Obj 3 is the time spent in the lower parts of the atmosphere to maximise the acquisition of relevant data during the re-entry. The delta-V required for the disposal from the operational orbit with a single burn was computed [2]. The apogee altitude is the starting altitude of the operation orbit and the perigee is the target for the Re-entry Analysis Phase. It was observed that starting from a 550 km orbit, with about 100 m/s delta-v it is possible to reach a perigee of about 180 km. During Phase A, a more detailed disposal analysis will be performed that will also consider a multi-burn strategy, to better distribute the delta-V of each burn and reduce the effects of possible misalignments or failures.

TECHNOLOGYCAL READINESS OF THE MISSION

Deriving from the objectives of the mission defined in the previous Section, the key technologies for the mission success consist of the three payloads dedicated to the fulfilment of the objectives, and of some subsystems whose technologies are qualifying for the success of the mission. Table 2 summarises the requirements of the main systems and subsystems of the CubeSat.

Table 2. Summary of main system and subsystem requirements.

ID	Requirement
CAM-1	The payload shall compute autonomously on-board the optimal CAM given the collision alert message (i.e. impactor state, covariance, and warning time).
CAM-2	The CAM shall be performed in less than one quarter of the period from the predicted close approach.
DEB-1	The PDD shall be able to detect sub-millimetre particles between 1 µm and 1 mm and characterise their dimension, velocity, and direction.
DEB-2	The PDD shall detect at least 200 particles, including both debris and meteoroids, during the operational time.
RDC-1	The RDC shall be able to measure the pressure and temperature of the atmosphere between 200 km and 100 km with a resolution of 10 km.
RDC-2	The RDC shall be able to characterise the thermal and mechanical loads sustained by the CubeSat during the disposal phase.
SYS-1	The CubeSat mass shall be less than 24 kg.
SYS-2	The CubeSat volume shall be less or equal than 12U.
AOCS-1	The AOCS shall provide a pointing accuracy of 1 deg during the Debris Analysis Phase.
AOCS-2	The AOCS shall provide a maximum slew rate of 1 deg/s.
AOCS-3	The AOCS shall provide a pointing accuracy of 5 deg during the Re-entry Analysis Phase.
PROP-1	The propulsion system shall provide at least 125 m/s for CAM and Re-entry Phase.
PROP-2	The maximum thrust of the propulsion system shall be 500 mN.
EPS-1	The EPS shall supply an average of 22 W and a peak of 29 W during the Debris Analysis Phase.
EPS-2	The EPS shall supply an average of 17 W and a peak of 53 W during the CAM phase.
EPS-3	The EPS shall supply an average of 18 W and a peak of 25 W during the Re-entry Analysis Phase.
COMM-1	The CubeSat shall be able to send telemetry data in the UHF/VHF frequency band for space application.
COMM-2	The communication system shall be able to download at least 600 kB/day during the Debris Analysis Phase, and at least TBD kB/orbit during the Re-entry Analysis Phase.

E.CUBE MISSION PAYLOADS

In this Section an overview of the payload technologies, their preliminary design, and their TRL will be given. To increase the modularity and reliability of the payloads, each one of them will carry a dedicated on-board computer, which will process the acquired data. Table 3 summarises the current TRL level of the payloads and the aimed TRL for Phase A/B.

Table 3. TRL level of the payloads.

Payload	Current TRL	Target TRL for phase A/B
CAM Command Module	HW 9 / SW 4	HW 9 / SW 6
Particle Detection Device	3/4	5
Re-entry Data Collector	3/4	5

CAM Command module

The payload for the CAM experiment is the CCM, a dedicated OBC implementing the algorithms for on-board CAM decision-making and design. The CCM only interacts directly with the CubeSat's OBC, receiving the synthetic CDMs sent from ground and navigation information, and generating a manoeuvre command when it determines a CAM is required. The CAM command will be handled by the OBC like a command sent from ground to perform a manoeuvre. The CCM will also log the key parameters related to the CAM decision-making and design process, and they will be transmitted to ground for analysis. The main objective of the CAM experiment is to advance the TRL and autonomy level of the on-board CAM algorithms and prove they can be used in future operational satellites. To this end, two criteria will be considered during the design of the CCM: 1) to make it as independent as possible from the platform, and 2) to clearly define the data interfaces with the OBC. The on-board CAM software is composed of 2 modules: the decision-making module and the CAM design module. The decision-making module determines whether a CAM is needed or not to keep the collision probability at close approach below a given threshold (typically 10-4) based on the sequence of CDMs and navigation information. It is based in machine learning algorithms, trained on ground with historical and synthetic CAM datasets. The CAM design module implements semi-analytical models for the efficient computation of maximum deviation or minimum collision probability impulsive CAMs2. The software implemented in the CCM will also include a supervision module, tasked with: 1) logging the principal parameters related to the operation of the other two modules, and 2) verifying that the generated CAM commands do not exceed a predefined operational envelope. Reference [5] shows a schematic representation of the CCM and the CAM software. The hardware selected for the CCM is D-Orbit's OBC Core, which is also selected as the OBC in the OBDH system. OBC Core has a TRL of 9, and it has been successfully implemented on the ION spacecraft. The CAM algorithm is currently at TRL 4, and during phase A/B it will be brought up to TRL 6 before its implementation in the CCM. Regarding the autonomy level, the objective is to demonstrate "ECSS-E-ST-70-11C – Space segment operability" level E4 autonomy during the in-orbit CAM experiment.

A preliminary estimation of the design parameters of the CCM is given in Table 4. The size, mass and power are based on those of the OBC Core. The expected data budget it very limited, including only the CDMs (maximum 3-4 per day) in uplink and the log of the CCM operation in downlink.

Table 4: Preliminary design of the CCM payload.

Parameter	Value
Size	15 x 15 x 2.5 cm^3
Mass	< 500g
Power	0.4 W (maximum 1.8 W)
Data volume	20 kB/day

Particle Detection Device (PDD)

In-situ space debris and meteoroids detectors developed so far are based on several physical principles. Among those, the most common systems employ strip-film conductive and piezoelectric materials. On one hand, strip-film sensors consist in a thin film of non-conductive material on which thin conductive stripes are deposed in parallel; in case of impact, the film is perforated, and one or more stripes are cut and their electrical continuity is interrupted [9]. By employing two layers it is possible to detect the position of the impact event, while the extent of the damage of stripes is used to estimate the properties of the impactor, and the sensitivity of the sensor depends on the density of stripes. On the other hand, piezoelectric detectors employ patches of piezoelectric materials (e.g. PVDF [10]) and measure the electric spike due to charge separation following the material deformation during the impact transient. The detection capability of piezoelectric sensors is currently in the range of 1 μm to 1 mm at a velocity of up to 10 km/s ; its sensitivity can be set by the conditioning electronics. Other systems proposed for debris impact detection come from direct heritage of scientific instruments for dust collection used in several space missions (e.g. Cassini, Stardust, BepiColombo, a detailed list is reported in Bauer et al. [11]) and employ acoustic sensors or piezoelectric panels to measure the momentum transferred to the payload during impact events. Such systems were developed to detect mostly dust and micrometeoroids with impact velocities and fluxes larger than those typical of space debris and require complex conditioning electronics. A sketch of the PDD that we are going to develop within e.Cube is shown in Figure 4. The PDD design will use existing solutions as baseline. During the execution of the e.Cube, the PDD technology maturity will be continuously increased through breadboarding and calibration activities, until the realisation and testing of a payload's proto-flight model during Phases C/D.

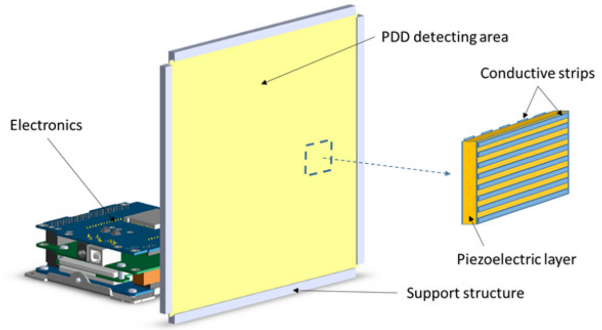

Figure 4: PDD schematic.

As baseline, we will evaluate the use of a piezoelectric detector sandwiched with two layers of conductive stripes. This combination will make possible to both cross-validate the two sensors and extend the working range of the detector through a proper adjustment of the sensitivity of the two elements. The detector will be backed by a soft material plate employed as debris catcher to avoid secondary signals due to debris cloud reflections and mounted on the satellite external structure. A first sensor breadboard will be developed in the flat-sat format for design-optimization purposes and will feature a scaled prototype of the PDD plate to be subjected to electric and functional testing. The driving and conditioning electronics will be realized as well. A second breadboard will consist in a more compact electronic box and a series of instrumented PDD plates with different configurations (e.g. thickness, layers material), to be evaluated by hypervelocity testing for full characterisation. The impact test campaign will make it possible to point out the best design solution and will calibrate the sensor in different working conditions in terms of impact momentum, debris size and velocity. It is underlined that calibration results could be also employed to improve the analysis of data collected by other sensors already in space. A preliminary estimate of the PDD SWAP in given in the Table 5:

Table 5: Preliminary design of the PDD payload.

Parameter	Value
Size (PDD plate)	18 x 18 x 2 cm^3
Size (PDD electronics)	9.2 x 9.7 x 4 cm^3 (CubeSat standard)
Total mass (plate+electronics)	1.3 kg
Power	5 W
Data volume	200 kB/day

Re-entry Data Collector (RDC)

The RDC has two main objectives:

- The measurement of the density, below 200 km altitude,
- The measurement of thermal and mechanical loads in the final mission phase before the re-entry.

First, the knowledge of the air density in the thermosphere is crucial for improving the accuracy of the SW models used to estimate the re-entry trajectory of debris. A first approach is identified in the direct measurement of the density in situ, which was typically performed with expensive payloads, not suitable for a CubeSat mission. Nevertheless, a second indirect approach can be considered: the density can be computed also as an indirect parameter after the measurement of other quantities, in particular temperature and pressure. The latter approach is suitable for CubeSat mission, being the temperature and pressure sensors for CubeSat already available on the market, and they do not need any development or customisations. The second objective of the RDC is the understanding of the thermal and mechanical loads acting on the CubeSat during the latest phase of its life. Inertial Measurement Units (IMUs) based on Micro Electro-Mechanical Systems (MEMS) technology are the state-of-the-art and several Commercial off-the-shelf (COTS) options are currently available on the market. The inclusion of temperature sensors and strain gauges to measure the internal heat loads and displacements, respectively, will be considered in Phase A, when a more consolidated internal design of the CubeSat will be available.

Since TEMIS heritage on space payload is based on systems larger than CubeSats, the currently developed products cannot be directly implemented in the CubeSat, but they require some customisations. For the RDC, a dedicated custom CPU board will be realised, exploiting the design heritage, including the COTS sensors and drivers to reduce costs and risks. The following sensors are considered in this preliminary assessment:

- Pressure sensor: A set of three pressure sensors will be used. As baseline, the MKS 905 MicroPirani sensors have been selected [2].
- Heat Flux Sensor: From the heat flux in the velocity direction the information about temperature of the flux can be computed. For the baseline, the Omega HFS-3 heat flux sensor has been selected [2].

PRELIMINARY SYSTEM DESIGN

The following sections present the preliminary mission design of the CubeSat for the main subsystems, considering the requirements arising from the payloads and the operational phases. When applicable, possible options for the equipment selection have been given, alongside the TRL of the components. Given the large availability of COTS with low prices and space heritage, the approach here is to select systems and components from Italian and European manufacturers. This reduces risks and allows to focus on the scientific and technological nature of the mission.

Structure and configuration

The structure of the spacecraft is a standard 12U CubeSat, which is compatible with the integration of COTS components. The preliminary configuration of the e.Cube spacecraft is shown in Figure 5. Some highlights are the presence of the PDD on the front face, and two deployable solar panels to guarantee the power production. On the back, the two main engines used for CAM and disposal manoeuvre are visible.

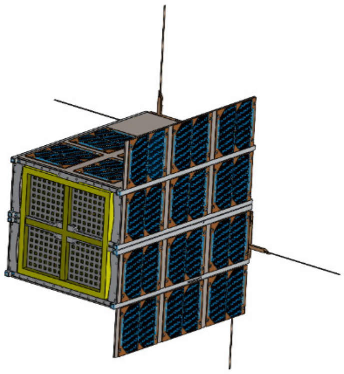

Figure 5. Front view of the preliminary configuration of the e.Cube spacecraft.

Attitude and orbit control system

The Attitude and Orbit Control System (AOCS) is a crucial subsystem for the success of the mission. During the CAM experiment the system shall ensure the correct orientation of the CubeSat to perform the manoeuvre in the direction specified by the algorithm. During the debris detection experiment, the ACDS shall ensure the RAM pointing of the CubeSat with an accuracy of 1 degree. During the re-entry analysis experiment, the system shall be able to maintain a data relay connection to download the acquired data until an altitude of 100 km. To ensure a correct attitude of the CubeSat during the mission lifetime, the system is controlled on the three axes with Reaction Wheels (RW). The de-tumbling is performed with magnetorquers. The desaturation control of the RWs is performed using together magnetorquers and, if needed, CubeSat attitude thruster module, relying on cold-gas thrusters, aligned with the Centre of Ma, thus minimising parasitic torques (nominally null). The following actuators architecture is considered in this preliminary assessment:

- Reaction Wheels: the RWs are selected among the commercial flight-proven available on the market. Four RWs, one for each axis plus a redundant one, are selected to make a 3-axis attitude control [2].
- Magnetorquers: the magnetorquers are selected among the commercial flight-proven available on the market. A three-axis magnetorquer will be carried on-board. They will be used to perform desaturation of the RWs [2].
- Attitude control module: the possibility of including a compact cold-gas thruster module will be evaluated during the Phase A of the mission if needed during the desaturation of the RWs. These modules can provide up to 10 mN of thrust along 2-axis at low power consumption (< 2W).

The attitude determination will be performed with flight-proven sensors. Given the currently available sensors for CubeSats, the expected accuracy of the attitude determination system is up to 0.05 degrees when star-trackers are included. A summary of the main components for attitude determination is given in [2].

The selection of the actuators is driven by the requirements related to the three operational phases, shown in Table 2. Preliminary analyses have been performed to estimate the maximum momentum storage and the maximum torque required during each one of the phases.

Propulsion system

The propulsion system design is crucial to the mission success as it will perform both the CAM and the disposal manoeuvres before the re-entry analysis phase. Given the requirements PROP-1 and PROP-2 (Table 2) a trade-off analysis has been performed on currently available CubeSat propulsion systems. The CAM experiment requires a minimum delta-V of 5 m/s. Considering a 5-minute burn to perform the CAM, the maximum required thrust level for one manoeuvre is 80 mN. The maximum delta-V required to change the orbit for the Re-entry Analysis Phase is 120 m/s, including margins.

Possible candidates for the propulsion system have been identified [2]. Given the delta-V requirements for the optimal strategy for the Re-entry Analysis Phase, the baseline propulsion system design foresees a set of two chemical thrusters. This option also guarantees a redundancy of the propulsion system and a sub-optimal disposal strategy for the Re-entry Analysis Phase in case of failure of one of the thrusters. In addition, it also allows a more responsive system during the CAM phase. An electric option can also be considered and in this case a single thruster will be used. A more detailed trade-off analysis will be performed during the Phase A.

Electrical power system

The electrical power system architecture for the e.Cube mission is based on solar arrays, secondary batteries and the power conditioning and distribution electronics. The EPS shall be sized based on the power and energy required during each mission phase. Power requirements for each mission phase are summarized in Table 6.

Table 6: Power budget summary for the main operational phases.

Phases	Avg. Power (W)	Peak Power (W)
CAM Phase	17	53
Debris Analysis Phase	22	29
Re-entry Analysis Phase	18	25

A preliminary sizing of the solar arrays was performed [2]. Considering the 22 W average power case, the required array area is about 900 cm^2. The analysis was performed considering as baseline orbit a dawn-dusk SSO to minimize the eclipse load on solar arrays and on-board batteries. During Phase A, a trade-off will be performed to analyse the possibility to carry the mission on a different orbital configuration. During the Debris Analysis Phase and the Re-entry Analysis Phase, the CubeSat will be RAM pointing; therefore, the solar panels will be placed on the 2-by-3 lateral side facing the Sun, together with a solar panel wing, to grant the desired level of power for the system. Additionally, to ensure the power generation in case of pointing misalignment and for redundancy reasons, solar cells will be placed on every lateral side of the CubeSat.

Mass budget

A preliminary Mass Budget is presented in Table 7, considering possible for the system components from the analysis presented above.

Table 7: Preliminary mass budget.

SubSys	Components	Mass (g)	Margin	Mass with margin (g)
P/L	PDD Payload	1300	20%	1560
	CAM Payload	500	20%	600
	RDC Payload	500	20%	600
STR	Structure	1750	20%	2100
PS	Propulsive System	2820	20%	3384
AOCS	Sun Sensors	8.8	20%	10.56
	Star Tracker	106	20%	127.2
	Gyroscope	55	20%	66
	Magnetometer	8	20%	9.6
	Magnetorquer	106	20%	127.2
	Reaction Wheels	940	20%	1128
	GNSS receiver	20	20%	24
	GNSS antenna	18	20%	21.6
C&DH	Main Computer	150	20%	180
TT&C	UHF Antenna	115	20%	138
	S-Band Antenna	110	20%	132
	UHF Transceiver	94	20%	112.8
	S-band Transceiver	270	20%	324
EPS	PCDU	191	20%	229.2
TCS	Thermal	315	20%	378
	Harness	315	20%	378
	Total	**9061.8**	**20%**	**10874.16**

CONCLUSION

The preliminary mission design for the e.Cube mission is presented. The e.Cube mission aims at contributing to the advancement of technologies and methodologies dedicated to space debris mitigation and remediation (1) to increase spacecraft autonomy in performing CAMs, (2) to support space debris modelling with in-orbit collected data about non-trackable fragment objects, (3) to characterise the atmosphere for more accurate re-entry predictions and the thermomechanical loads experienced by the spacecraft during re-entry. The proposing team will engage with other European and extra European companies, institution and agencies for enlarging the e.Cube consortium.

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