Title: Hermes CubeSat: on-site data gathering for accurate mapping of the Main Asteroid Belt.

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(x) We apply for Student Prize.
(   ) Please keep our idea confidential if we are not selected as finalists/semi-finalists.

Abstract: The purpose of Mission Idea Contest 7 (MIC7) is to propose an innovative mission idea that contributes to deep-space science and exploration. This proposal mission consists of a 9U CubeSat equipped with a long-range radar. It targets the Main Belt, where the goal will be to detect asteroids in the 100-300m range and map their orbits using the same communications system as the PROCYON's (ISAS/JAXA). This way, it is expected to update the current data for this range of size and, potentially, detect new, unclassified asteroids. This mission will prove the deep-space capabilities of CubeSats and its components. In addition, it is expected to ease the path for further science missions and, potentially, asteroid-mining missions. This proposal was developed by 4 students of Kyushu Institute of Technology (KIT).

1. INTRODUCTION

In the last decades, CubeSats and nanosats have gained much importance. Technology miniaturization has made them an interesting alternative to conventional satellites. This has given space access to many countries that otherwise would struggle to put a satellite in orbit or, simply, would not be able to do it. Access to space for these countries liberates them from relying on other countries and boosts the economy. [1] The next step is deep space. This mission aims to test and prove technologies in a deep space environment.
The constant innovations in space technologies, together with an increase in the interest for future asteroid mining prospects, have driven many companies to trace plans and strategies. Eventually, it will become profitable, and this mission aims to increase the data bank of the Main Belt to ease future asteroid mining.

The provided launcher has enough delta-V to carry the spacecraft to the Main Belt. The CubeSat will carry a thruster for small orbit adjustments and a second one set for attitude control. The trajectory (cf. figure 1) is a highly elliptical orbit around the Sun. Its apogee is inside the Main Belt and the perigee is at 1AU. The mission is divided into 3 phases: stand-by (S), operations (O), and transmissions (T). The S phase goes from the launch to the Main Belt, where the spacecraft will be dormant. Then, the O phase, where the instruments are used, and data is collected. Once the spacecraft is at an optimal distance from Earth, the T phase begins, where data is sent to the ground station.

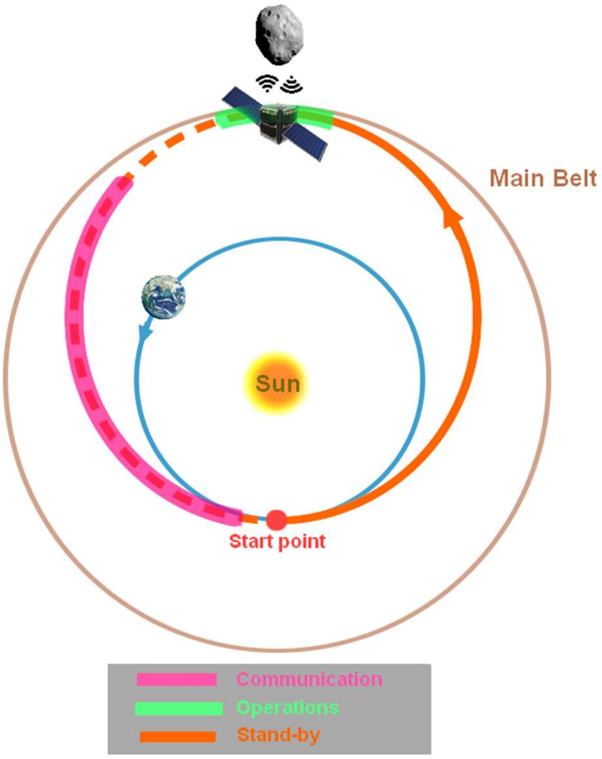

Figure 1: Diagram of the orbit (Not to scale)

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Past on-site asteroid missions found that the asteroid differed from the initial expectation, which derived mainly from ground observation [2]. Notable examples are Ryugu (Hayabusa 2) and Ultima Thule (New Horizons).

Currently, it is relied upon estimations for computing the number of bodies in the Main Belt [3]. Mapping asteroids from the Main Belt has been proven to be unfeasible. By getting closer, the population of the small asteroids can be precised and the current data for the larger bodies can be refined [4].

-Detect and map asteroids in the 100-300m range with a Sun-centered reference system.
-Refine the existing data for asteroids above 300m diameter.
-Demonstrate CubeSat capabilities in a deep-space environment.

2. MISSION OBJECTIVES

2.1 Radar detection

During phase O, the detection mission starts. Raincube was a NASA project using a miniaturized Ka-band radar for earth observation [5]. Table 1 shows its characteristics.

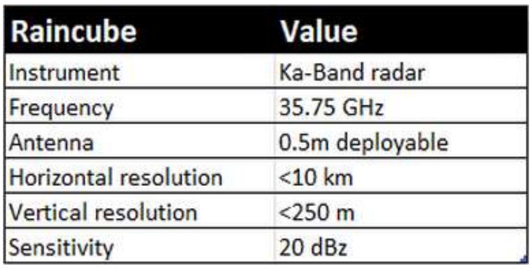
This radar is used to send and detect a 35.75GHz signal. The collected information is:

-Doppler effect.

-Time delay (delta T).

-Magnitude.

Table 1: Characteristics of Raincube's radar



Raincube	Value
Instrument	Ka-Band radar
Frequency	35.75 GHz
Antenna	0.5m deployable
Horizontal resolution	<10 km
Vertical resolution	<250 m
Sensitivity	20 dBz

The radar deploys from a 1.5U slot to a 2.5U antenna. and has a resolution of a tenth of a degree, which is enough to compensate for the satellite's displacement during delta T (which is about a hundredth degree). This radar is not commercially available. Hence the need to build a radar adapted to the mission with the same technology.

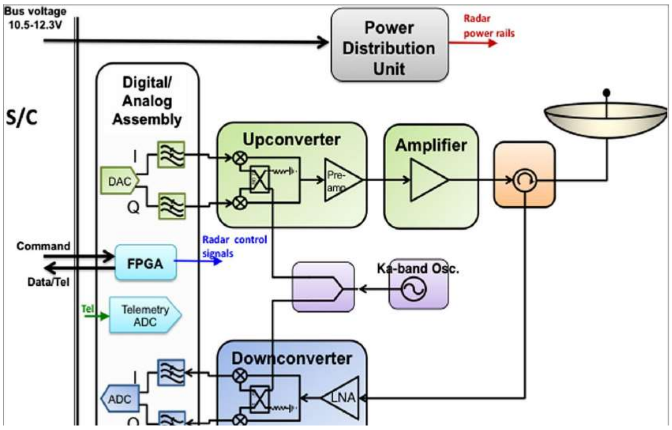
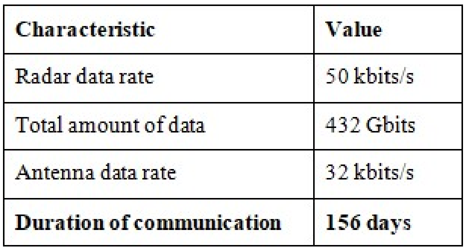


Figure 2: Block diagram for the Raincube radar

2.2 Earth communication

During phase T, the satellite sends the collected data from the previous observation to Earth. The signal will be a simple comparison between the sent signal and the received signal. The data rate of the radar is 50kbits/s after treatment [6]. The table 2 shows the data which must be sent to the Earth ground station.

Table 2: Communication data characteristics



Characteristic	Value
Radar data rate	50 kbits/s
Total amount of data	432 Gbits
Antenna data rate	32 kbits/s
Duration of communication	**156 days**

An algorithm integrated into the CPU onboard applies filters for erasing any noise or echo in the signals before their storage. A compression algorithm will accelerate the processing speed.

The deliverable is communicated by radio frequency to the Earth ground station during 8 continuous hours of communication per day (cf. *Conditions of MIC7 contest*) as soon as the onboard transponder PROCYON [8] signal can reach the Earth. It has a telemetry bit rate range from 8 bits/s to 32 kbits/s.

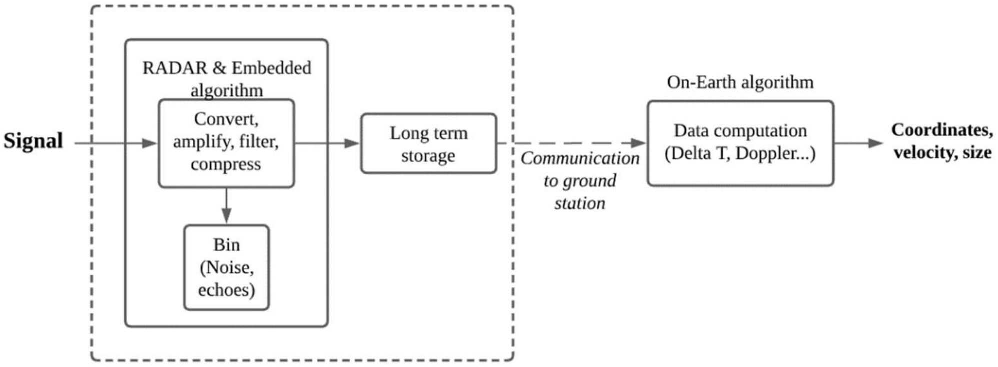


Figure 3: Data flow chart between CubeSat and ground station

2.3 Optimal orbital injection

The CubeSat will be able to achieve only a few orbits around the sun. The selected orbital maneuver is a single impulse maneuver. This orbit is described with the orbital parameters in table 3. Figure 3 shows its shape.

a	2.99x10^8	*km*
b	2.59x10^8	*km*
e	0.5	-
T	2.83	*years*
ΔV	6.69	*km/s*

The fly-by zone is in a corridor 2% the total radius of the Main Belt, as described in figure 4. The derived time spent in the main belt is 100 days.

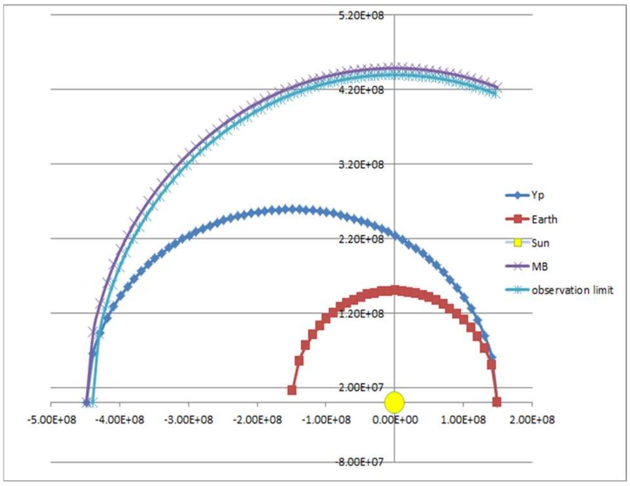


Figure 4: observation limit orbit (distances in km)

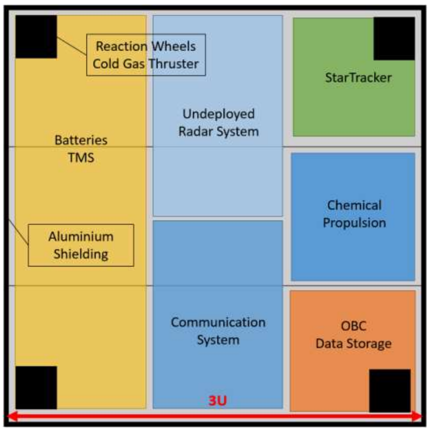
2.4 Data collection and analysis

The collected data is analyzed on Earth ground station. The position, velocity, and size of the objects can be computed. This information is stocked in a data bank.

However, the data has a finite lifetime, since the gravitational effect of Jupiter and Yarkovsky drift effect change the orbital properties of the asteroids, depending on their size and distance from the Sun. In a paper by David A. Minton and Renu Malhotra [7], most of the asteroids over 30km diameter are not influenced by the Yarkovsky effect. For objects between 10km and 30km, it would take between 10 and 1000 years to deviate from their orbit. In the end, the data of the less stable asteroid can be valid for a maximum of ten years.

4. KEY PERFORMANCE PARAMETERS

Table 3: Spatial distribution of components.



1. Orbital injection: achieve at least one fly by. This fly-by must allow one full observation of the desired area of the Main-Belt. This would be done by calculating the proper ballistic with the associated initial speed.
2. Data quantity: minimize the quantity of data stocked by processing the raw information.
3. Schedule: the phases described in the introduction must follow a specific schedule, so the observation, communication, and stand-by have a defined occurrence time and period.
4. Stability of the orbit: keep a stable orbit. This parameter must be satisfied by the addition of thrusters that would help correct the orbit if necessary.

5. SPACE SEGMENT DESCRIPTION

5.1 Thermal management

Deep space is a challenging issue on thermal and radiation management of the satellite since the orbit will range from 1AU to as far as 3AU. Thus, adequate radiation shielding, and thermal management has been explored.

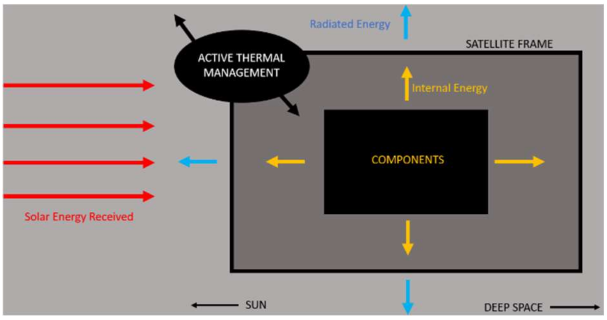


Figure 5: Heat exchanges of the satellite

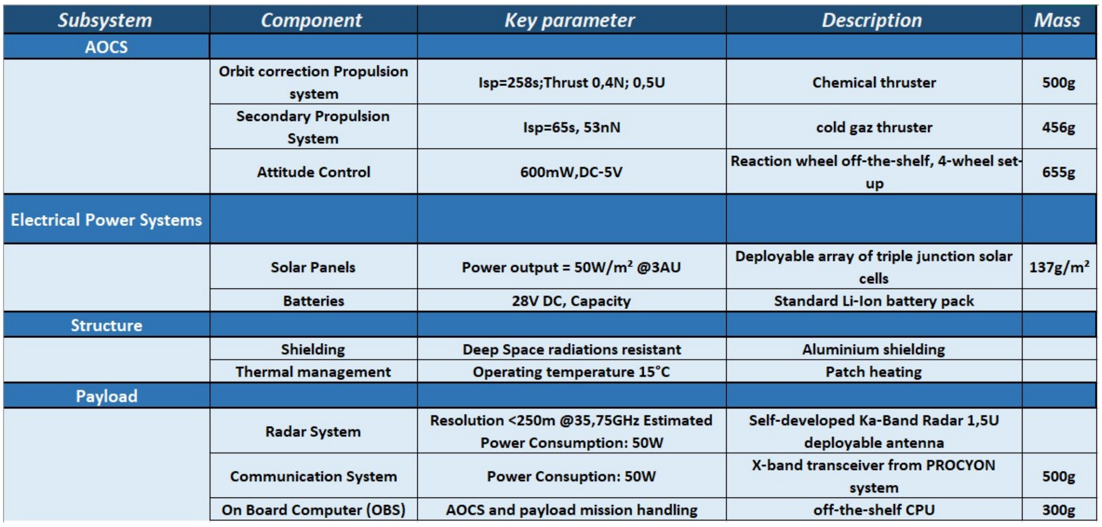
First, due to the extended orbit of the mission, thermal transfer has been considered from a steady state point of view. The satellite will also always have a unique side facing the Sun as seen in figure 6.

Thermal management of the CubeSat is composed of patch heating and insulating material as active and passive thermal management.

The CubeSat will be exposed to harsh radiative environment; it will thus be equipped with aluminum shielding to protect the OBC and batteries for the duration of the mission.

5.2 Equipment and subsystems

Table 4 List of subsystems.



Subsystem	*Component*	*Key parameter*	*Description*	*Mass*
AOCS				
	Orbit correction Propulsion system	Isp=258s;Thrust 0,4N; 0,5U	Chemical thruster	500g
	Secondary Propulsion System	Isp=65s, 53nN	cold gaz thruster	456g
	Attitude Control	600mW,DC-5V	Reaction wheel off-the-shelf, 4-wheel set-up	655g
Electrical Power Systems				
	Solar Panels	Power output = 50W/m² @3AU	Deployable array of triple junction solar cells	137g/m²
	Batteries	28V DC, Capacity	Standard Li-Ion battery pack	
Structure				
	Shielding	Deep Space radiations resistant	Aluminium shielding	
	Thermal management	Operating temperature 15°C	Patch heating	
Payload				
	Radar System	Resolution <250m @35,75GHz Estimated Power Consumption: 50W	Self-developed Ka-Band Radar 1,5U deployable antenna	
	Communication System	Power Consuption: 50W	X-band transceiver from PROCYON system	500g
	On Board Computer (OBS)	AOCS and payload mission handling	off-the-shelf CPU	300g

6. CONCEPT OF OPERATIONS

This project has been set to start at the beginning of the year 2022. All the main activities are listed in table 7, which shows a top-level project schedule to summarize the duration of the activities involved in the project. The total duration is 695 days, almost 2 years.

To visualize the duration of the project and the interaction between activities, figure 7 shows a Gantt diagram of the project.

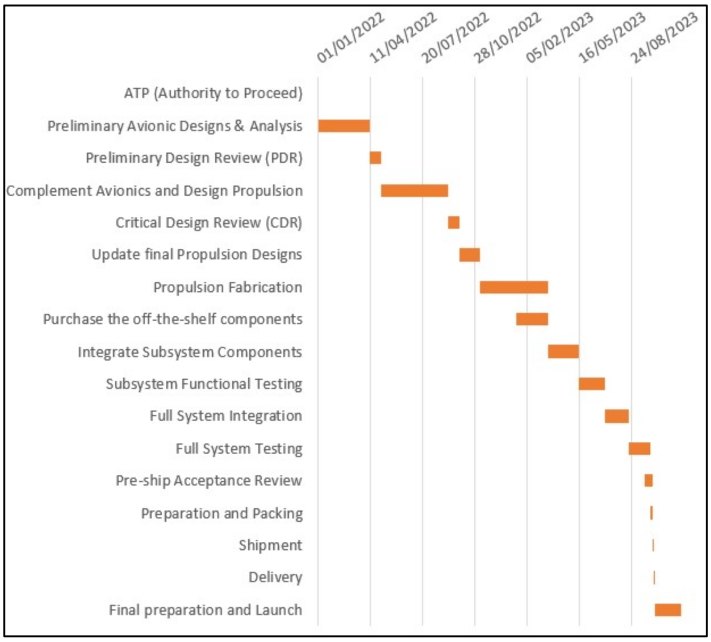


Figure 6: Gantt diagram of the project.

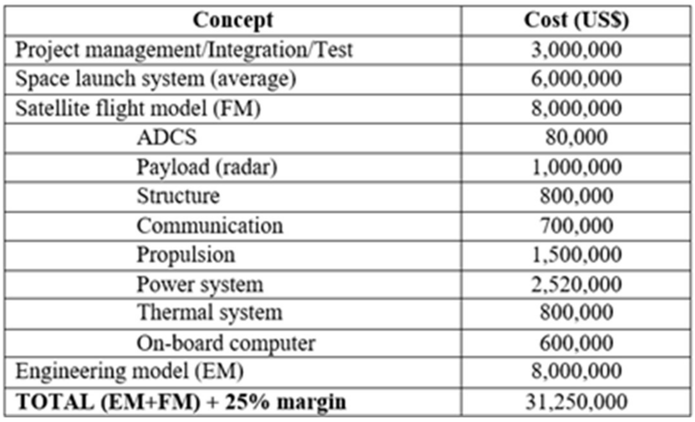
7. IMPLEMENTATION PLAN

7.1 Total life cycle cost

Based on the already few existing projects of CubeSats in deep space, such as *Mars Cube One* MarCO (6U, 13.5 kg, Mars mapping, no return on Earth) which had a total cost of 18.5 million USD [10]. The total life cycle cost including design, development, components assembly, integration, testing, launch, and operation (***NB:*** a return is not necessary) of the CubeSat into the Main Belt is estimated at 28~32 million USD (cf. Table 8).

7.2 Facilities

Table 5: Estimation of the total life cycle cost



Concept	Cost (US$)
Project management/Integration/Test	3,000,000
Space launch system (average)	6,000,000
Satellite flight model (FM)	8,000,000
ADCS	80,000
Payload (radar)	1,000,000
Structure	800,000
Communication	700,000
Propulsion	1,500,000
Power system	2,520,000
Thermal system	800,000
On-board computer	600,000
Engineering model (EM)	8,000,000
TOTAL (EM+FM) + 25% margin	31,250,000

All the operations related to the assembly and tests (thermal, radiation, environment interaction, mechanical, etc.) of the subsystems and structural parts will be held on the campus of Kyushu Institute of Technology (Japan). Keeping the same locations for every phase reduces the development time, cost and minimizes the mission risk factors. Furthermore, inside the facilities, there are all the materials required for the development of the designing phase. The workload is divided into several groups of people; tasks are divided and can be carried out efficiently and simultaneously. Specifically, 32 people: 9 people in the mechanical team, 8 people in the thermal team, 5 people in the solar array team, 4 people in the onboard computer team, 3 in the orbit and attitude control team, 2 people for management and 1 expert in payload. As part of the project, the supervisors of the scientific and engineering teams will work together to ensure that the satellite will be able to meet all its mission requirements and avoid any changes in the nature of the missions.

7.4 Top 3 project risks and their possible countermeasures

1. The inside of the Cube Satellite is facing too low a temperature in the Main Belt, the components cannot work properly.

As a countermeasure, an additional unit of thermal management composed of heater films is included in the organization of the component.

2. The capacity of the memory storage is not sufficient regarding the collected data and the sorting of it.

As a countermeasure, one additional memory storage (with half the capacity of the main one) will be integrated into the unit of data storage.

3. During the testing phase of the satellite, one facility damages the CPU (Sudden stop in the satellite development).

As a countermeasure, two CPUs are bought, with the same references and the same program implemented.

8. REFERENCES

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