32th Satellite Design Contest Satellite Overview

Application category

Design Section

1. Work information/Applicants information

Work title (less than 20 words) Green Experiment Nutrient Enrichment System In Space (GENESIS)		
Subtitle (Only when you wish to make a special case. This may be removed from official documents.)		
	Name	Affiliation including faculty, department (Lab) and year of study
Group representative	CHUAN, WEN-JUI	National Cheng Kung University International Bachelor Degree Program on Energy Engineering, Year 4
Group representative (Sub)	CHEN, YI-XIANG	National Cheng Kung University International Bachelor Degree Program on Energy Engineering, Year 4
Member 1	HSU, CHAO-WEI	National Cheng Kung University International Bachelor Degree Program on Energy Engineering, Year 4
Member 2	CHEN, BO-SHEN	National Cheng Kung University Department of Aeronautics and Astronautics, Year 2
Member 3	HUANG, YU-HUAN	National Cheng Kung University Department of Aeronautics and Astronautics, Year 2
Member 4	TAM, CHAK-FAI	National Cheng Kung University Department of Life Sciences, Year 3
Member 5	HUANG, SONG-FENG	National Cheng Kung University Department of Electrical Engineering, Year 5
Member 6		
Member 7		
Member 8		

2. Outline of the satellite (approx. 200 words)

GENESIS is a 50cm cube microsatellite with a mass under 50kg, designed to establish the first self-sustaining microalgae cultivation system in space for bio-waste treatment. Key features include:

- Mission: Cultivate *Chlorella vulgaris* microalgae in polar orbit to evaluate bio-waste usage efficiency in the high-radiation space environment over 10-12 months.
- Payload: Includes cultivation tank, culture medium storage tank, measurement box, waste tank, LED lights, pH probe, dissolved oxygen sensor, micro camera, and 680 nm light detector to monitor microalgae growth.
- Structure: Aluminum alloy frame with additional isolation box to protect the cultivation tank from being directly killed by radiation. Solar panels mounted on sides.
- Orbit: Polar orbit to maximize radiation exposure with a semi-major axis of 7199.99 km and inclination of 78 degrees, which we want to see the growth of microalgae under a space radiation environment.
- Systems: Includes reaction wheels and thrusters for attitude control, thermal control to maintain 18°C ± 2°C, and power system with solar panels and batteries.
- Data collection: Parameters like optical density, dissolved oxygen, pH, and radiation levels were measured twice daily and downlinked during passes over ground stations.
- Innovation: First fully automated, multi-generational microalgae cultivation mission in space, aimed at advancing bio-waste processing for long-term space travel.

3. Mission requirement (Aims of satellite) and significance

(a) Mission requirement (Aims of satellite)

- Establish the first self-sustaining microalgae cultivation system in polar orbit for space bio-waste treatment.
- Cultivate Chlorella vulgaris to evaluate its efficiency in processing bio-waste under high-radiation space environments.

- Achieve automated, multi-generational cultivation of microalgae over 10-12 months.
- Collect data such as optical density (OD), dissolved oxygen (DO), pH value, bio-waste element content, and radiation equivalent, measured twice daily.
- Establish cultivation conditions for Chlorella vulgaris in the space environment.
- Utilize polar orbit to maximize radiation exposure and downlink data at perigee.

(b) Importance, technical significance

- Address the issue of bio-waste management for future space travel and space colonization.
- Develop a self-sustaining bio-waste system in space, reducing human resource needs.
- Conduct the first long-term, multi-generational automated microalgae cultivation experiment in space.
- Explore microalgae adaptability to microgravity and high-radiation environments, laying the groundwork for future use as space food and fuel.
- Promote interdisciplinary collaboration between aerospace engineering and biological sciences, paving the way for innovative interdisciplinary space missions.
- Reduce maintenance costs and human resource requirements for space experiments through automation.
- Provide crucial technological support for life support systems in long-term space travel.

4. Anticipated results

We expect to see significant growth of microalgae in the space environment compared to that on Earth, which means higher waste processing efficiency. Also, we anticipate the fully automated experimental design to operate smoothly. If we can successfully design an automated microalgae cultivation system, it will play a crucial role in future long-term space travel. Not only will it allow for successive generations of microalgae cultivation, but the automated system will also reduce the need for human maintenance of the equipment in space, significantly lowering maintenance costs.

5. Originality and/or social effects

The mission of GENESIS is the first fully automated, multi-generational cultivation mission for microalgae. This mission aims to revolutionize the handling of vital human metabolites during long-term space travel and provide a continuous nutritional source for space food, significantly contributing to the increasingly prevalent field of space travel. Furthermore, the mission of GENESIS spans both aerospace engineering and biological sciences, adopting an interdisciplinary approach to encourage future academic and industrial collaboration across various fields with aerospace engineering. This will pave the way for more innovative interdisciplinary space missions, marking a significant advancement in the history of human space exploration.

6. Result of satellite design

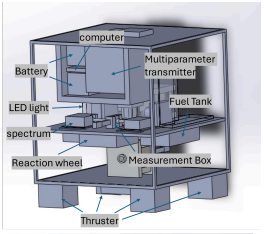
(a) System (overall configuration, shape, mass, function, operational orbit)

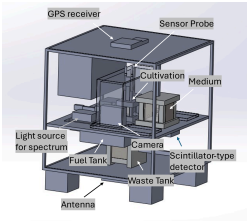
Orbit type	SMA	ECC	INC
Polar orbit(LEO)	7199.9km	0.0837	78 deg
RAAN	AOP	TA	Shape & Mass
0 deg	0 deg	0 deg	50cm cube under 50kg

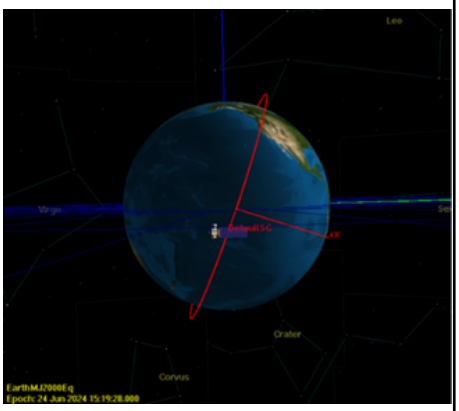
(b) Experimental system including ground stations

Ground station:

Hsinchu ground station	SSC Space US Dongara
Taiwan (25°N, 121°E) Assets: 7.2m	Australia (30°S, 115°E) Assets: 13m
Svalbard satellite station	NASA's White Sands Ground Statio, New Mexico
Norway (78°N, 15°E) Assets: 9m,13m	USA (33°N, 106°W) Assets: 18.3m





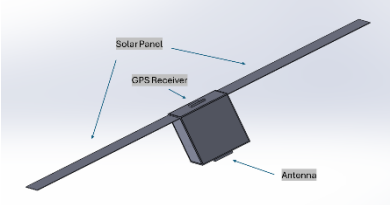


(c) Operational procedure including data acquisition

Orbit Insertion: Launch into polar orbit (7199.99 km semi-major axis, 78° inclination).

Cyclical Mission Phases (10 cycles):

Section 1. Cultivation: Pump medium 40ml, inoculate Chlorella vulgaris, maintain 18°C, 3000 LUX, 16:8 light cycle.
Section 2. Measurement: Twice daily, collect DO, pH, OD, images, and radiation data.
Section 3. Subculture: At OD 0.5, remove 36ml in the cultivation tank, add fresh medium, and retain 4ml for the next cycle.
Data Acquisition: Collect measurements twice daily during light cycles.
Data Transmission: Downlink during passes over four ground stations.
Environmental Control: Maintain 18°C ± 2°C, control LED lighting.
Power Management: Use solar panels, and manage distribution.
Attitude Control: Use thruster and reaction wheel.
Data Analysis: Generate growth curves, assess bio-waste processing efficiency, and evaluate radiation impact.



7. Concrete achievement methods, range, and budget for manufacturing

Satellite Structure:

50cm cube microsatellite	Mass under 50kg
hexagonal structure Aluminum alloy material	Additional isolation box to protect the cultivation tank

Payload:

Cultivation Tank	Culture Medium Storage Tank	Waste Tank
LED lights	pH probe	DO sensor
measurement box	Micro Camera	680nm light detector

Systems:

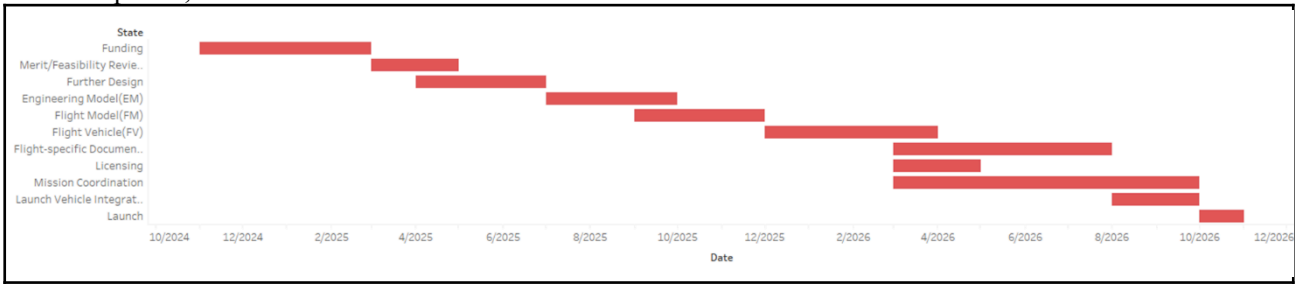
Attitude control	Thermal control	Power	Data transmission
IFM NANO Thruster and RW-0.06 Reaction Wheel	Maintain 18°C ± 2°C	Solar panels and batteries	X-Band transmitter

Range:
The satellite is designed to operate in a polar orbit for 10-12 months, conducting 10 cycles of microalgae cultivation and data collection.

Budget:

Components	Estimated cost (USD)	Components	Estimated cost (USD)
Structure	30000	GPS Receiver	3200
Computer	12000	Antenna	3200
Battery (EPS)	35000	Camera	2000
Transmitter	25000	Probe	2000
Thruster	42000	Geiger Counter	1500
Reaction Wheel	35000	Spectrum System	3000
Solar Panel	30000	Total	223900

8. Development, manufacture and launch schedule



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1. Aims and purposes of the satellite

The main goal of the microsatellite Green Experiment Nutrient Enrichment System In Space (GENESIS) is to establish a pioneering self-sustained system for microalgae cultivation within the polar orbit, thereby addressing the imminent issue of space life waste.

The very first aim of establishing this system is to cope with the biowaste in space for future space travel or even space clones. To fulfill this ambition, a micro-algae self-sustained system can play a key role in the waste management system. For example, microalgae can decompose urea in urine excreted by the human body and absorb it as a nitrogen source. These self-sustaining microalgae systems need to be testified under space conditions to prove the amount of microalgae that can be maintained. The mission will compare two different conditions, one that is exposed to space radiation and ultraviolet rays and the other that is carried out on Earth. In previous space biological culture experiments, most of them were short-term cultures of a single generation. However, in our mission, each group will reproduce in ten subcultures and will last around ten months to one year. To plot and compare the growth curve of microalgae, some data, including photos, pH values, oxygen concentration, and radiation equivalent, will be collected to prove the growth curve of the microalgae inside the satellite. Furthermore, another key focus of our mission is "automation." Based on previous biological experiments conducted in space, most of them have taken place on the International Space Station (ISS). This not only limits the experimental scope to a single environment but also necessitates the involvement of at least one astronaut to participate and maintain the experiment due to the lack of automation, thereby increasing the workforce costs required for the experiments. If we can successfully design an automated microalgae cultivation system, it will play a crucial role in future long-term space travel. Not only will it allow for successive generations of microalgae cultivation, but the automated system will also reduce the need for human maintenance of the equipment in space, significantly lowering maintenance costs. Therefore, automation is an essential part of our mission.

Due to the mission's focus on biological cultivation, it is essential to consider the fluidic system comprehensively, as numerous fluids will flow within the apparatus. Fluidic-based instruments are, therefore, indispensable. We will reference previous missions, such as GeneSat-1, PharmaSat, O/OREOS, SporeSat, and EcAMSat, to identify the fluidic-based instruments we require. With technological advancements, the fluidic systems designed for newer space missions have become more complex and sophisticated. Currently, BioSentinel possesses the most complex and multifunctional fluidic system, as it is the first biological CubeSat mission to be conducted in deep space. BioSentinel incorporates advanced technologies such as internal check valves, desiccant chambers, and bubble traps. We will design our system based on the technologies utilized in this mission.

Biologically, microalgae are regarded as a promising candidate for space missions due to their high efficiency in carbon dioxide fixation and oxygen release, with potential applications that go far beyond waste treatment. In addition to their role in waste treatment, microalgae can be used as food

and fuel, both essential for space travel. Studying their behavior in high-radiation environments can help in designing more resilient and sustainable ecological life support systems, providing vital ecological support for long-term space missions. Additionally, our mission can lay the groundwork for future Chlorella research in space. Therefore, we aim to observe the growth of Chlorella vulgaris in this high-radiation environment. Based on the research we found, Chlorella vulgaris has sufficient radiation resistance to withstand the radiation levels at our mission's target orbit. Although radiation at this altitude may inhibit growth rates, it will not lead to lethal accumulation or immediate death of the algae during cultivation. Given these conditions, our mission seeks to establish the necessary parameters for cultivating microalgae in the natural space environment and to develop a system that can automatically culture microalgae. This will contribute to the future scientific development of microalgae in space.

Therefore, the mission of “GENESIS” is to establish the first self-sustaining microalgae cultivation system on a satellite for bio-waste treatment in space. This system will operate in the polar orbit, recording microalgae growth performance to evaluate bio-waste usage efficiency under a high-radiation space environment and is expected to achieve the following goals:

1. The goal is to create a self-sustaining bio-waste system in space, reduce human resource needs for waste management, and evaluate the feasibility of using microalgae-based systems for life support in future deep space exploration endeavors.
2. Chlorella Vulgaris is selected for the bio-waste system due to its high growth rate and efficient nutrient uptake capabilities, providing insights into the resilience and adaptability of biological systems under extreme conditions.
3. Parameters such as OD, DO, pH value, bio-waste elements, and radiation equivalent will be measured. Visible light photos of microalgae growth will also be taken to record microalgae growth patterns and morphological changes over time.
4. Data on these indices will be collected two times daily and downlinked during each revisit, allowing for real-time monitoring and analysis of the experiment's progress.
5. Establishing the Cultivation Conditions for Chlorella vulgaris in the Space Environment, taking into account factors such as microgravity, radiation exposure, and temperature fluctuations.
6. Polar orbit is chosen for the maximum radiation exposure that can be received by the satellite, enabling a comprehensive study of the effects of space radiation on microalgae growth and bio-waste processing efficiency.
7. The mission lifetime is expected to be 10 to 12 months, allowing for multiple generations of microalgae cultivation and providing a long-term dataset on space-based biological processes.

2. Design result

2.1 Orbital Analysis

The orbit design for GENESIS is a polar orbit due to the concentrated radiation levels found in polar regions. Earth's magnetic field lines run predominantly from north to south, encompassing the planet in a protective shield. This magnetic field is crucial for deflecting charged particles from the solar wind, which would otherwise bombard and potentially harm Earth's atmosphere and surface. These factors lead to higher radiation intensity in the north and south magnetic pole regions, which have also become important indicators for our orbit design.

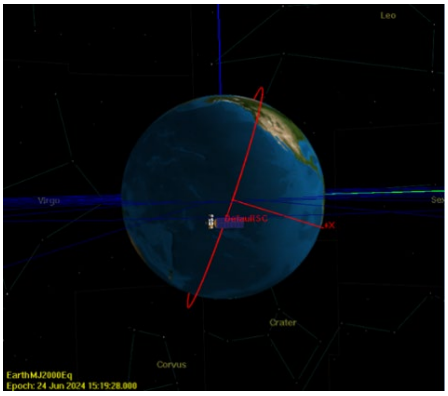


Figure.1 Orbit Analysis

Our mission want to put the microalgae on the environment with high radiation(we will focus on gamma rays) seeing what will happen to the microalgae and we look forward to getting some results that can help in future space missions.

We choose the orbit for that it will pass through a high-latitude area which overlap with radiation belts and polar areas. In such an environment, the satellite will be exposed to higher cosmic rays, including gamma rays, which will provide the necessary conditions for studying the radiation tolerance of microalgae. And for not killing the microalgae, we use SPENVIS to ensure the cumulative dose will not exceed 1000Gy(this dose may kill the microalgae from knowing paper), and the orbit will pass through fixed station about 15 times a day , we will have lots of time to get the data, because we need to record and collect the data at least once a day.

We then do the orbit radiation simulation in the Space Environment Information System (SPENVIS), we can model the radiation of different orbits, and after consideration, we define the orbit referring figure below:

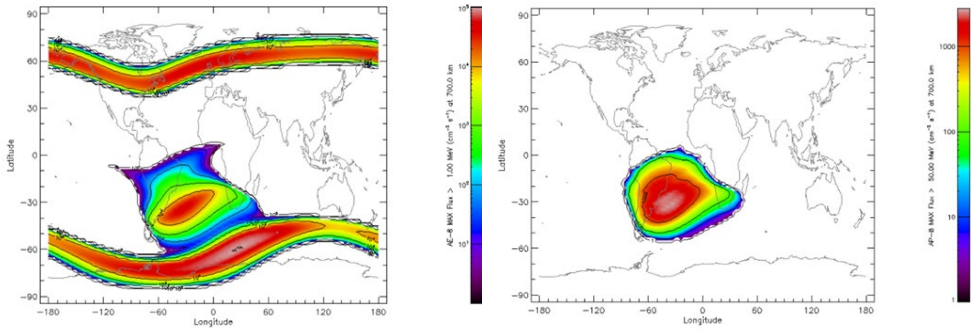


Table.1 Simulation of protons and electrons radiation

Table.2 Polar orbit elements of the GENESIS mission

Element	amount
Semi-major axis	7199.99 km
Eccentricity	0.0837
Inclination	78 deg
Longitude of the ascending node	0
Argument of periapsis	0
True anomaly	0

Ground segments:

The ground facility will include four ground station which are Hsinchu ground station(25°N, 121°E), SSC Space US Dongara, Australia(30°S, 115°E), Svalbard satellite station(78°N, 15°E), NASA's White Sands Ground Station, New Mexico(33°N, 106°W), the duration time of satellite that passes through these four station each day in average is in table below:

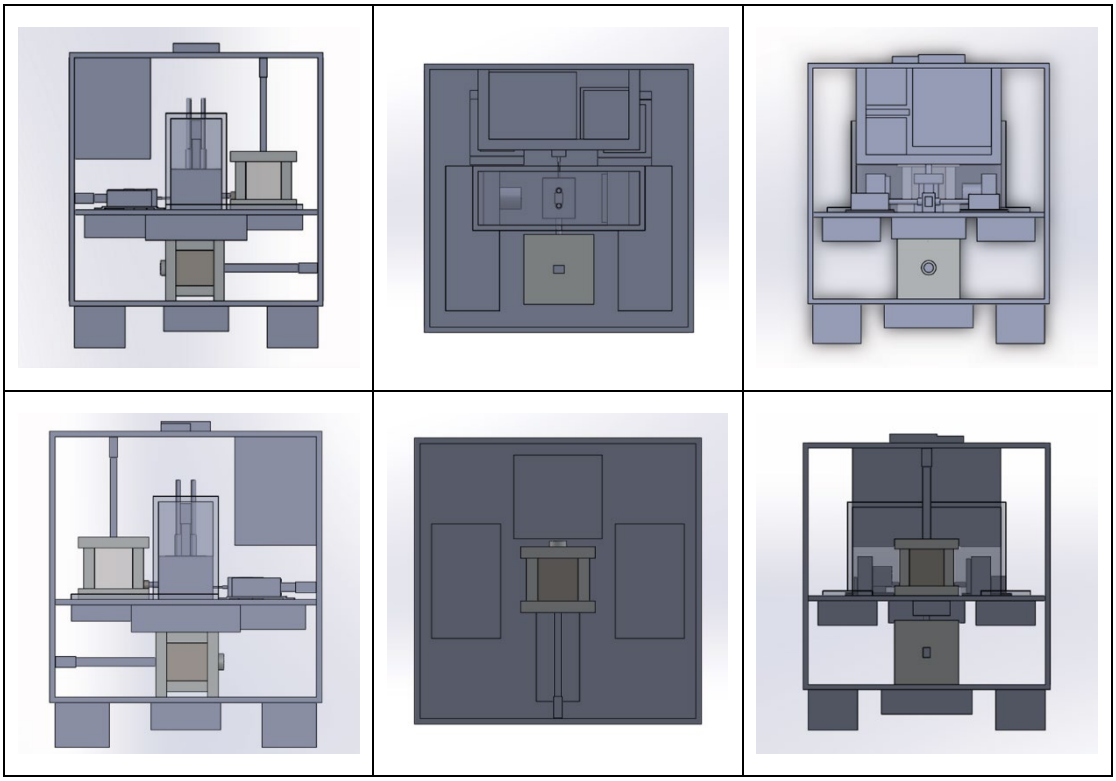
Table.3 (simulation by GMAT)

Ground station	Duration time (each day on average)
Hsinchu ground station(25°N, 121°E)	2155.2sec
SSC Space US Dongara, Australia(30°S, 115°E)	2294sec
Svalbard satellite station(78°N, 15°E)	6648.74sec
NASA's White Sands Ground Station, New Mexico(33°N, 106°W)	2380.7sec

We choose Svalbard satellite station to be operating station for that KSAT operates two polar ground stations optimized for low Earth orbit (LEO) satellites. This is the only one of two ground stations able to see a polar-orbiting satellite on every revolution. From 2004, the Svalbard Undersea Cable System gives two redundant fiber lines to the mainland, each providing 10 gigabits per second.

2.2 Structure design

Table.4 Different perspectives



We will set the automatic experiment equipment for microalgae cultivation in the satellite structural design, in Figure 2 and Figure 3 shows the internal equipment setup of the experiment design. Due to the restriction of the H II-A rocket, the size of the satellite will be a cubic 50cm side length, the weight will be under 50kg mainly composed of aluminum alloy material. The components are labeled in Figure 2 and Figure 3. The solar panel will be installed on the sides of the satellite, and the energy conservation will be managed due to the system requirement. With the consideration of space radiation, we want to measure the growth of microalgae under a space radiation environment, but in case the high energy density, we add an isolation box to protect the cultivation tank from being killed directly from space radiation.

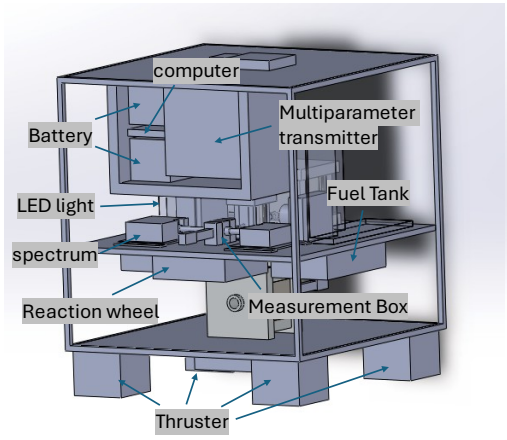


Figure 23 Structure Design

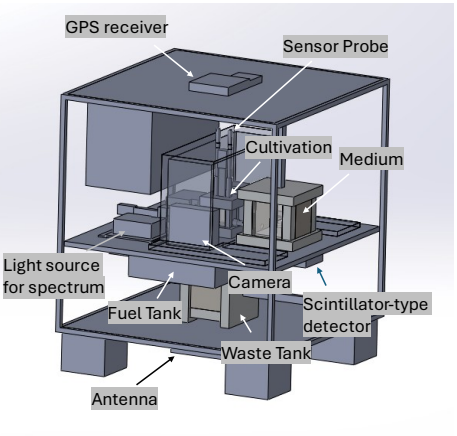
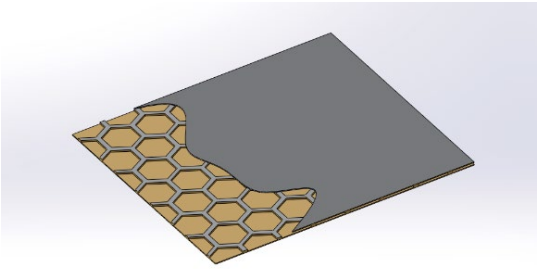


Figure 32 Structure Design

The parameters we choose to measure include the dissolved oxygen, pH value, and optical density, which will be used to monitor the growth of microalgae. A Scintillator-type detector will be applied to measure how much space radiation the satellite receives.



Figure,4 Multilayer insulation on side wall

To lower the weight and to protect the microalgae from being straightly burnt by space radiation, the side walls that insulate the satellite will be designed with a hexagonal structure aluminum plate covered by multilayer insulation materials shown in Figure 4. The side wall will play a critical role in satellite weight distribution, the hexagonal structure will decrease the weight of aluminum usage by around 90%, which can provide more weight budget for other important design components. The multilayer insulation material can provide great protection and maintenance of the structure's operation temperature.

2.3 Mission Design

The effects of microgravity and space radiation

Firstly, concerning the effects of microgravity, our research indicates that exposing *Chlorella vulgaris* to a radiation-filled microgravity environment impacts its cellular repair mechanisms. (1) Additionally, as mentioned in the Orbital Analysis section, *Chlorella vulgaris* can withstand cumulative radiation levels up to approximately 1000 Gy. Of course, as radiation levels increase, its growth rate slows accordingly. These two unique space conditions lead to reduced growth rates in *Chlorella vulgaris*, primarily due to gamma radiation's biological impact on cell components, especially water molecules. Gamma rays interact with the growth medium to generate free radicals, which can alter cell composition. However, at the radiation doses we anticipate, cells may sustain slight damage but still maintain normal repair processes. Moreover, protein synthesis decreases with rising radiation doses, potentially enhancing the photoinhibition of photosynthesis and thus further suppressing *Chlorella vulgaris* 's growth rate. (2) These conclusions, however, are based on short-term experiments. In our mission, we will conduct serial cultures of *Chlorella vulgaris*, where radiation's impact may alter its genetic structure. This could enable subsequent generations of *Chlorella vulgaris* develop stronger resistance to the space environment—a result we hope to observe through our experiment.

Reflecting genetic stability through growth rate

Exposing *Chlorella vulgaris* to the space environment may raise concerns about genetic stability, but we do not intend to return the samples to Earth for genetic stability assessment, as the costs of retrieval are too high. Instead, we will assess genetic stability by comparing *Chlorella*'s growth rate. We believe that genetic stability in organisms is first reflected in growth rate, which is why we aim to measure optical density during cultivation to generate a growth curve and calculate changes in *Chlorella*'s growth rate across different periods and generations, using this formula:

$$\mu = \frac{\ln(OD_2) - \ln(OD_1)}{t_2 - t_1}$$

OD1 and OD2 are the absorbance values measured at times t1 and t2, respectively, with (t2−t1) as the interval between measurements.

Preliminary experiment

Due to the volume limitations of the satellite, our mission's cultivation volume for *C.vulgaris* is capped at 40 ml. Cultivating *C.vulgaris* at this scale involves potential scaling effects, so we plan to conduct a test cultivation to confirm successful growth within this specified volume. To ensure feasibility, we consulted an on-campus laboratory specializing in microalgae research to conduct preliminary experiments. The actual cultivation procedure is as follows:

Condition

- Strain: Chlorella sorokiniana
- Initial OD_{750}: 0.05
- Volume: 40 mL
- State : static
- Room Temperature: 28C

The laboratory collaborating with us provided *Chlorella sorokiniana*, which is similar to *Chlorella vulgaris*, for our experiments. Thus, we determined it was feasible to use this species in the preliminary experiment. We conducted the cultivation in two groups: one using the standard BG-11 medium, and the other adding additional Na2HCO3 (4 g/L) to the BG-11 base. In both groups, we placed an initial OD value of 0.05 of algae in a 40ml container, left it at 28˚C in a static and non-aerated environment, figure have shown the culture conditions, and the results showed successful cultivation in this volume (data provided by Professor I-Son Ng's lab at National Cheng Kung University), with meaningful pH and absorbance data obtained. Figure 5 have shown the result.

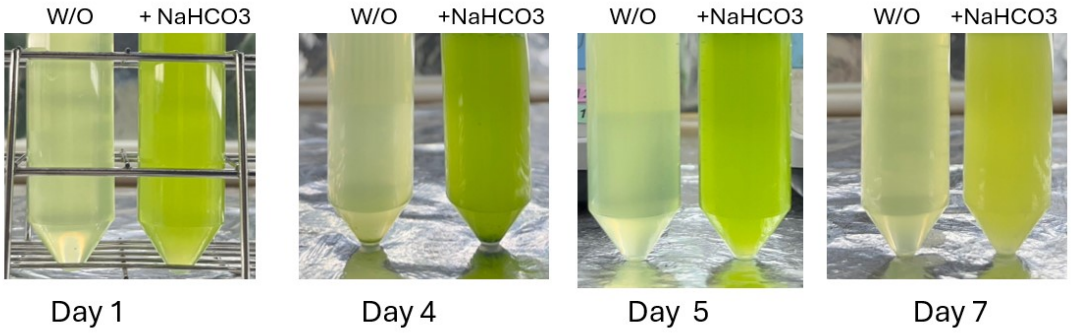
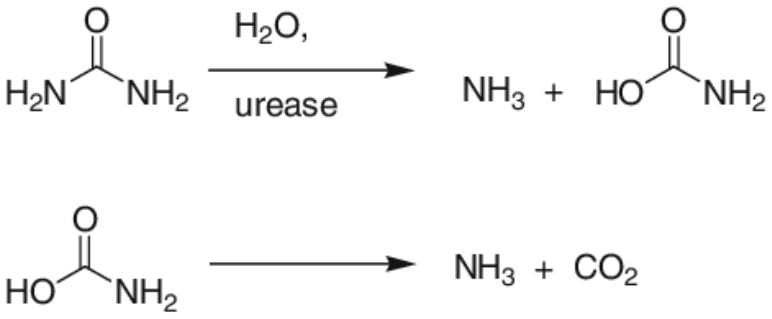


Figure 5. the result of preliminary experiment
(Data provided by Professor I-Son Ng's lab at National Cheng Kung University)

It is clear that both experimental groups were able to successfully cultivate *Chlorella.*

Medium management

The management of the culture medium is crucial to our project. We will use various sensors to collect culture data, with a primary focus on monitoring pH changes. In fact, pH variations provide us with valuable information, such as insights into carbon dioxide control. Instead of using the traditional BG-11 medium, we replaced its nitrogen source with urea. During cultivation, this medium releases ammonia and carbon dioxide, the latter of which will be fixed by *Chlorella vulgaris*.



We anticipate that ammonia will gradually raise the pH of the culture medium during cultivation, and the preliminary experiment confirmed our hypothesis.

Table.5 Medium conditions

Medium	OD750	pH
BG11	0.103	8.92
BG11 with NaHCO3 (4 g/L)	0.418	12.12

In actual space cultivation, since we will transfer *Chlorella vulgaris* to the measurement box and waste tank to supplement fresh culture medium, we predict that pH fluctuations will have minimal impact on the overall culture process. However, as a precaution, when sensors detect that the pH of the culture medium exceeds a certain threshold or if we observe anomalies in the data, we will have a manual or automated method in place to replenish the medium and stabilize its pH level. For example, when the pH of the medium in the Cultivation Tank exceeds 8, we will add fresh medium to neutralize the pH (approximately 1.4 ml is sufficient to bring it back to pH 7).

2.4 Mission Payload

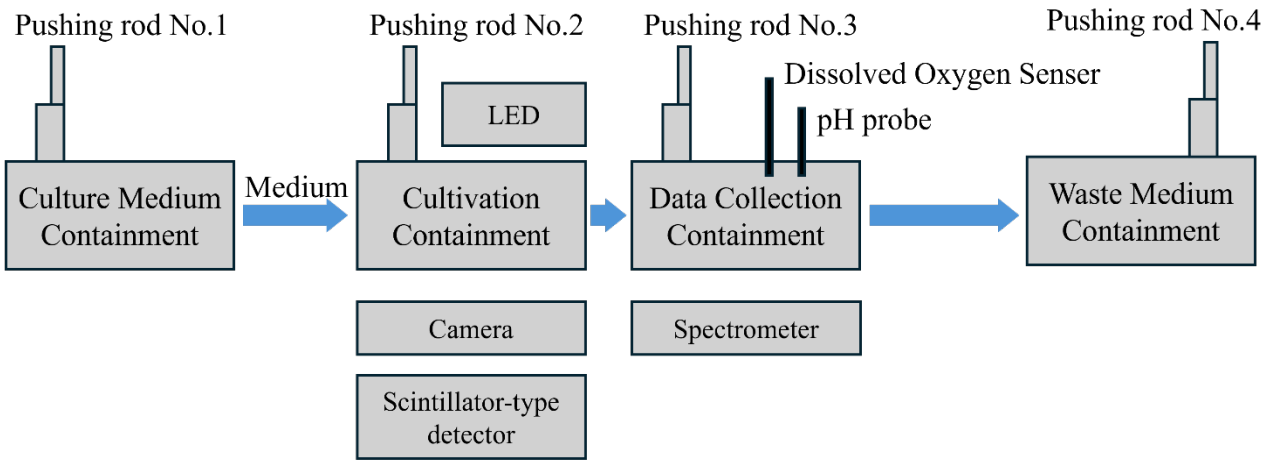


Figure.6 Mission payload

I. Cultivation Tank, Culture Medium Storage Tank, Waste Tank, Measurement box

To accomplish this mission, the key lies in cultivating microalgae. Automating the cultivation of microalgae controlled by the computer on the satellite is not a simple task, so we designed the apparatus based on the fundamental experimental process, which includes the Cultivation Tank, Culture Medium Storage Tank, and Waste Tank.

First is the Cultivation Tank. The dimension (W x H x D) of Cultivation Tank is 4 x 4 x 2.5 cm. Since microalgae cultivation is the focus of our mission, we need to ensure a proper growth environment for the microalgae. We will designate a specific area within the tank for cultivating microalgae, which will not only prevent contamination from other impurities during growth but also facilitate subsequent data measurements. The Cultivation Tank, with a capacity of 40mL, is designed to fulfill this purpose. Next is the Culture Medium Storage Tank. To perform serial cultivation of microalgae, it is essential to ensure that the microalgae and their progeny have sufficient nutrients. Therefore, for our long-term cultivation mission, the Culture Medium Storage Tank is indispensable. In other words, the amount of culture medium stored in the Culture Medium Storage Tank essentially determines how long our apparatus can operate.

When *Chlorella vulgaris* reaches the logarithmic growth phase, we will begin the Subculture Phase. We can determine the timing for subculturing based on the received data. When the returned data shows that the measured OD value reaches 0.5, we will start the next generation of *Chlorella vulgaris* cultivation. Thus, our Mission Phase returns to the Cultivation Phase, repeating the cycle continuously. The Waste Tank is responsible for storing the used culture medium and microalgae. Due to the limited cultivation space, it is necessary to transfer a portion of the microalgae to the Waste Tank before each subculture proceeds with the next generation of microalgae cultivation and retain approximately 4 ml of the medium. Then, we will add fresh medium. This step also simulates the practical use of microalgae for food and fuel production, where a portion of the microalgae is removed from the Cultivation Tank, leaving a small amount for subculture.

The measurement box is where we perform absorbance measurements. The dimension (W x H x D) of the measurement box is 2.5 x 2 x 1 cm. Since taking absorbance measurements requires a contamination-free environment to ensure accurate readings, we designed a dedicated space for this purpose. After taking the absorbance measurement, the microalgae and culture medium are pumped back into the Cultivation Tank.

II. LED

According to our mission requirements, cultivating microalgae necessitates a light source for photosynthesis. In other words, we need to install LED lights internally. The reason for using LED lights is that we need a stable light source, whereas using sunlight might result in uneven illumination for the microalgae. Additionally, since we plan to use a 16:8 light-dark cycle for microalgae cultivation, using LED lights is more energy-efficient compared to installing switchable shutters on the satellite's exterior. Based on previous cultivation studies, 3000 LUX lighting is most effective for the growth of microalgae. The specifications of the LED light are summarized in Table.6.

Table.6 Properties of LED light

Material	Aluminum
Dimension (W x H x D)	4 x 4 x 1 cm
Illuminated Area	4 x 4 cm^2
Illuminance	3000LUX
Power Consumption	12W
Mass	100g

Figure.7 LED light

III. pH sensor

To monitor the growth of microalgae, we need several data points to support our observations, and one of these is the change in the medium's pH value. Organisms typically have a specific pH range for optimal growth, within which their enzymes are more active, thus promoting better growth. This applies to *Chlorella vulgaris* as well. Our initial pH value will be set at pH 5.5. By observing changes

in pH values and comparing them with the microalgae growth curve, we aim to demonstrate the feasibility of our mission.

Figure.8 pH sensor

We will use the Digital Non-Glass pH Sensor Memosens CPS77E to measure pH levels. Unlike glass electrodes, ISFET-type pH electrodes have no risk of glass breakage, making them suitable for space experiments. They can withstand high-temperature and high-pressure sterilization and disinfection, allowing for stable long-term measurements. The principle of the ISFET sensor is based on the field effect of semiconductors, where pH is measured by detecting changes in ion concentration on the electrode surface. The sensitive area, covered with an ion-sensitive material, reacts to changes in hydrogen ion (H^+) concentration.

Table.7 Properties of pH probe

Measuring Principle	ISFET
Characteristic	Digital, sterilizable and autoclavable pH electrode for hygienic production processes with bacteria tight ceramic junction
Measuring Range	pH 0 to 14
Operating Temperature	-15 to 135°C
Operating Pressure	Max. 11 bar abs at 100 °C
Diameter	12mm
Shaft lengths	120 mm
Mass	100g

IV. DO sensor

We use the Digital Dissolved Oxygen Sensor DO-8200FD to measure dissolved oxygen levels. This digital sensor utilizes the principle of fluorescence for detection. This technique takes advantage of the quenching effect of oxygen on fluorescence. When a specific wavelength of light is directed onto the oxygen-containing water sample, oxygen absorbs some photons and re-emits new ones, producing a fluorescence effect. The optical sensor in the dissolved oxygen analyzer measures the fluorescence signals emitted by oxygen after absorption. Based on the measured fluorescence intensity, it infers the oxygen concentration in the water sample. By using the DO sensor, we can monitor the growth of the microalgae and the rate of photosynthesis. The specifications of the DO sensor are summarized in Table.8.

(DO-8200GD)

Figure.9 DO sensor

Table.8 Properties of DO sensor

Measurement Parameter	Oxygen
Measuring Principle	Fluorescence
Measuring Range	0.01~20mg/L
Resolution	0.01mg/L
IP rating	IP68
Sensor Diameter	12mm
Sensor Length	70mm
Operating Pressure	0～4Bar
Measuring Temp. Range	0~60ºC
mass	100g

V. DO/pH meter

Generally, using a pH probe and a DO sensor requires a transmitter to display the measured data. We have chosen the M800 Multi-channel Transmitter for data conversion. It supports multi-parameter transmission, allowing us to transmit both pH and DO data simultaneously through a single device. The specifications of the DO/pH meter are summarized in Table.9.

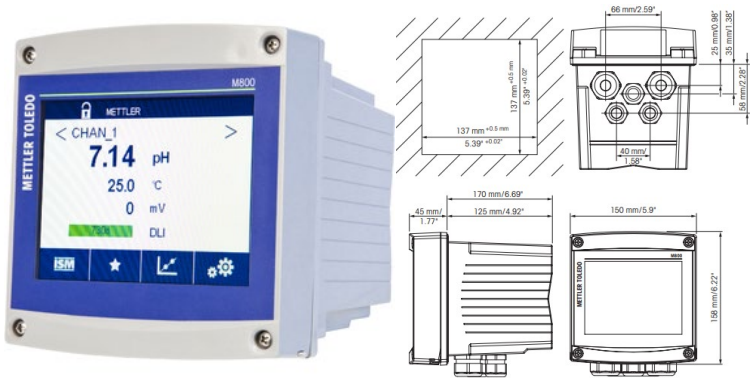


Figure.10 DO/pH meter

Table.9 Properties of DO/pH meter

Measurement Parameter	pH, DO
Size	163 × 163 × 168 mm
Operating Temperature	− 20 – 50°C
Mass	2.8kg

VI. Micro camera

For our mission, relying solely on data curves to observe the growth and waste processing efficiency of microalgae may be insufficient. For *Chlorella vulgaris*, there is a simpler method to confirm its

viability by checking its color. Under normal conditions, *Chlorella vulgaris* appears green, but as it grows, it gradually changes to yellow and then dies. This is a situation we want to avoid, as the most crucial aspect of subculturing is the survival rate.

In this context, using a micro camera to monitor its growth is the most reliable method. A micro camera can serve as a secondary safeguard for our mission, allowing us to visually confirm the microalgae's growth and compare it with the growth curve. This provides stronger evidence to prove the feasibility of our mission. We use Blackmagic Design Micro Studio Camera 4K G2 for our mission. The specifications of the micro camera are summarized in Table.10.

Figure.11 micro camera

Table.10 Properties of micro camera

Operating Temperature	0 – 40°C
Dimensions (W x H x D)	8.4 x 6.6 x 6.96 cm
Image Sensor	17.78 x 10 mm (Four Thirds) CMOS
Sensor Resolution	Not Specified by Manufacturer
Shutter Type	Mechanical Focal Plane Shutter and Electronic Rolling Shutter
Data storage	Computer
Operating system	Windows 10, 64-bit, Windows 11, 64-bit
Mass	300g

VII. 680nm LED, Filter and Detector

During the cultivation of *Chlorella vulgaris*, we will simultaneously create a growth curve. Measuring the concentration of cultured microalgae is crucial for generating this curve. Typically, a spectrophotometer is used for this task; however, it is not feasible to bring a full spectrophotometer into space. Therefore, we aim to replicate the operating principles of a spectrophotometer to conduct these measurements for us.

We will use the Beer–Lambert law to calculate absorbance values:

$$A = -\log_{10}\frac{I_t}{I_0} = \log_{10}\frac{1}{T} = K \cdot l \cdot c$$

In this context, A represents the absorbance, K is the molar absorption coefficient, l is the path length of the absorbing medium (cm), and c is the concentration of the absorbing substance (g/L or mol/L). The thickness of the absorbing medium is related to the dimension of measurement box.

The operating principle of the spectrophotometer is illustrated in the diagram, with the diffraction

grating being a key component. The grating is used to select light at a specific wavelength from the light source. This selected light is then directed onto the sample. After passing through the sample, the light reaches the detector (a sensor chip), which records the data (such as by transmitting it to a computer for data collection).

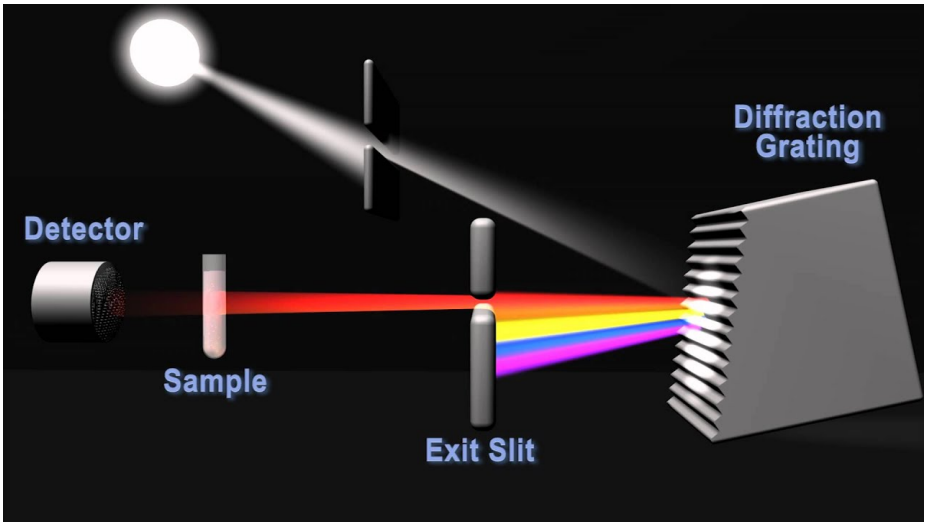


Figure.12 Mechanism of detector and filter

To simplify the spectrophotometer design for our mission, our goal is to replace the light source with a 680 nm LED, as we only need to measure absorbance at 680 nm. This approach will save space that would otherwise be allocated for a diffraction grating. However, using an LED could introduce potential issues with light source stability. To address this, we will pair the LED with a 680 nm filter to improve the device's measurement precision and ensure accurate absorbance readings. Additionally, we will use opaque tubing to connect the light source and the detector, ensuring that the light is shielded from external environmental influences during transmission. This setup will help prevent any interference or fluctuations in the light signal, maintaining the accuracy and stability of the measurements. By minimizing external factors, we can ensure that the readings reflect only the light absorbed by the sample, leading to more reliable and consistent data. Prior to setup, the detector will be calibrated to enhance accuracy further.

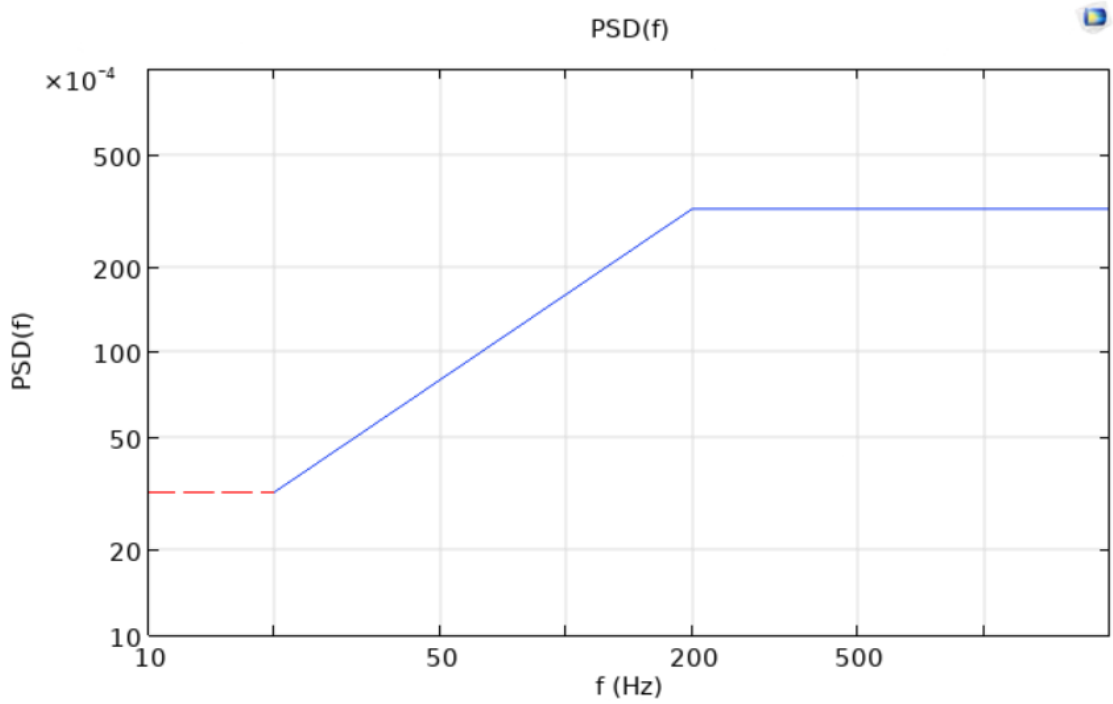
We will use PDR-V468 TO-5 photodiode as our detector, which is commonly employed in such applications. Its working principle involves converting received light signals into electrical signals. After light of a specific wavelength passes through the sample, its intensity decreases. This attenuated light then reaches the photodiode's photosensitive surface. The photodiode's photosensitive area absorbs incoming photons (light energy) and converts them into electrons (charge). When photons strike the photodiode material, they release electrons, generating a photocurrent. The strength of this current is proportional to the intensity of the incident light. This current is then amplified and converted into a numerical signal, which displays the sample's absorbance. The specifications of the Light Detector are summarized in Table.11.

Table.11 Properties of PDR-V468 photodiode

Operating Temperature	-15°C ~ 70°C
Peak sensitivity wavelength	680nm
Response Time	1μs
Current - Dark (Typ)	10pA
Diode Type	PIN
Voltage - DC Reverse (Vr) (Max)	100 V
Mounting Type	Through Hole
Package / Case	TO-5 Variant, 2 Leads, Lens Top Metal Can

2.4 Structural analysis

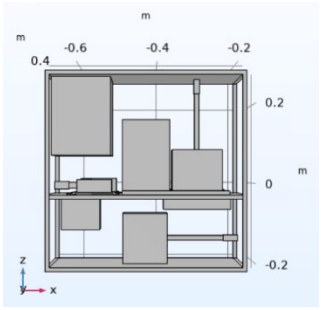
Random vibration (3-axis common)		
20～200Hz	+3db/oct	Effective value
200～2000Hz	0.032G2/Hz	7.8Grms



Sine wave vibration level	
Axis direction	2.5 Go-p (5～100Hz)
Axis orthogonal direction	2.0 Go-p (5～100Hz)
Quasi-static acceleration	
Axis direction	+5.0/-6.0G
Axis orthogonal direction	±5.0G

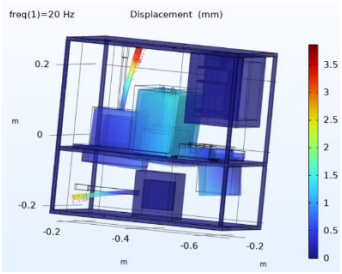
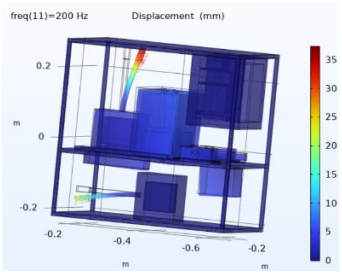
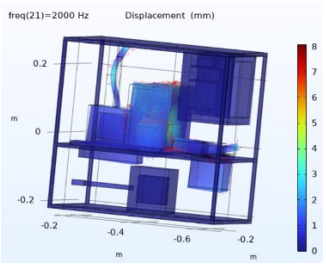
Rigidity requirements	
Thrust direction	higher than 120Hz
Lateral direction	higher than 60Hz

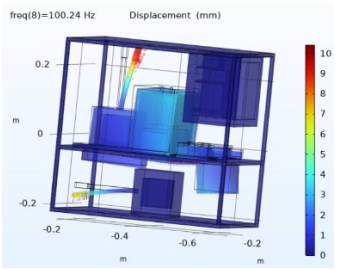
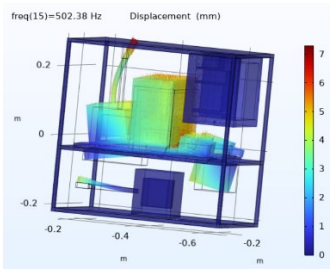
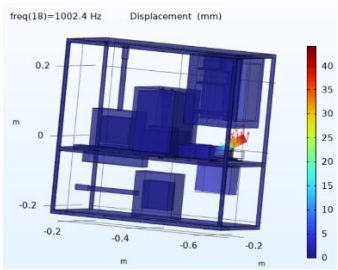
Definition of satellite coordinate:

	-X	The direction in which the thruster is pointing
	-Z	Direction directly below the earth
	+Z	The direction the GPS antenna is pointing

For the simulations of the satellite, we did the conditions in COMSOL Multiphysics and used a simplified model to reduce the complexity of the simulation calculations. The simulation will be done in four parts, random vibration, sine wave vibration, static acceleration, and thermal control, the material chosen is aluminum.

I. Random vibration

20Hz	200Hz	2000Hz
		
100Hz	500Hz	1000Hz

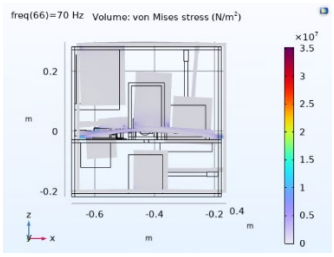
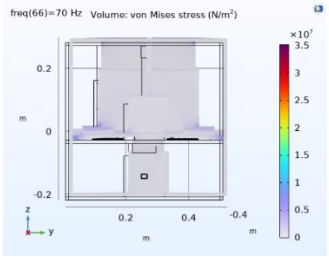
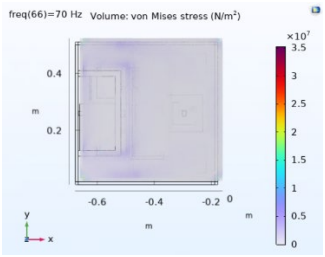
In the simulation of random vibration, as the PSD function given

$$20Hz \leq f \leq 200Hz, \qquad PSD(f) = 0.0032 \times \frac{f}{20} G^2/Hz$$

$$200Hz \leq f \leq 2000Hz, \qquad PSD(f) = 0.032\, G^2/Hz$$

With the load applied on three axes, we can derive the result of the structure deformation with different frequencies. In most of the conditions, the deformation of the satellite is not that significant on the structure, so it is acceptable for the structure design to pass through the random vibration.

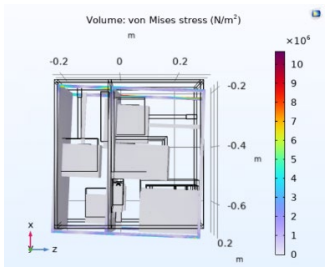
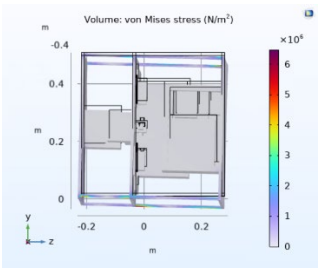
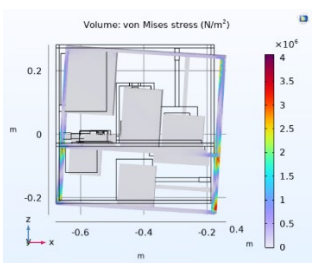
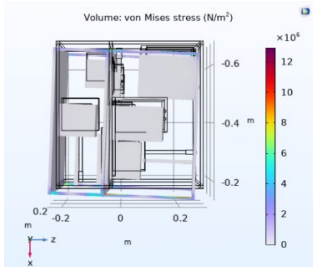
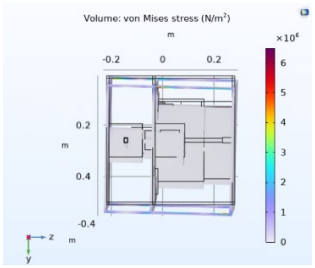
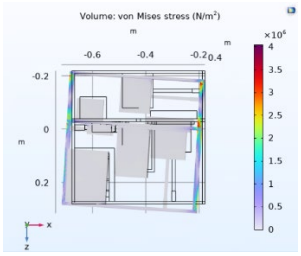
II. Sine wave vibration

x-z plane	y-z plane	x-y plane
		

For the sine wave vibration segment, the axis direction is +X axis, and the 2.5G is applied in the X direction, and the 2.0G is applied in the Y, Z direction.

The result of the load on the structure shows the pressure on the body, it mainly concentrates on the center part, and the deformation is under an acceptable range.

III. Static acceleration

X: +5.0G	Y: +5.0G	Z: +5.0G
		
X: -6.0G	Y: -5.0G	Z: +5.0G
		

In the static acceleration segment, we applied the acceleration body load in six axes of the satellite, and the results show in the form of direction upwards.

The result of the static acceleration shows the pressure load on the structure, and through the result of deformation we can tell the simulation is acceptable for the structure to pass the situation.

IV. Orbital thermal load and operation temperature

In the simulation of orbital thermal loads, we figured out that the operational environment in space should range between 200 and 1000 Kelvin.

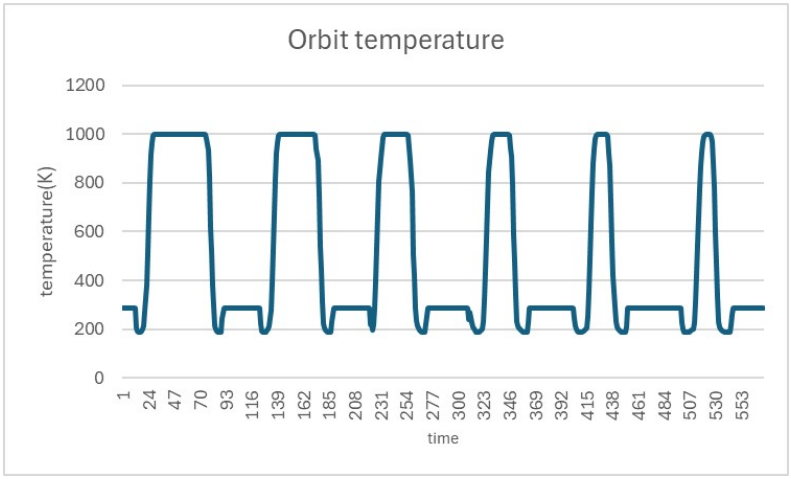


Figure.13 Orbit temperature analysis

To protect from this temperature, the satellite is covered with multilayer insulation. Additionally, the operational temperature will be regulated through thermal control using the heater and by designing the structure for effective heat conduction.

For the temperature simulation conducted in COMSOL, the primary heat distribution will occur in

the central part of the structure, where the cultivation experiment equipment will be located. The temperature control for cultivation should be maintained at 18°C ± 2°C, while temperatures can be lowered to around 0°C for other equipment due to their optimal operating conditions.

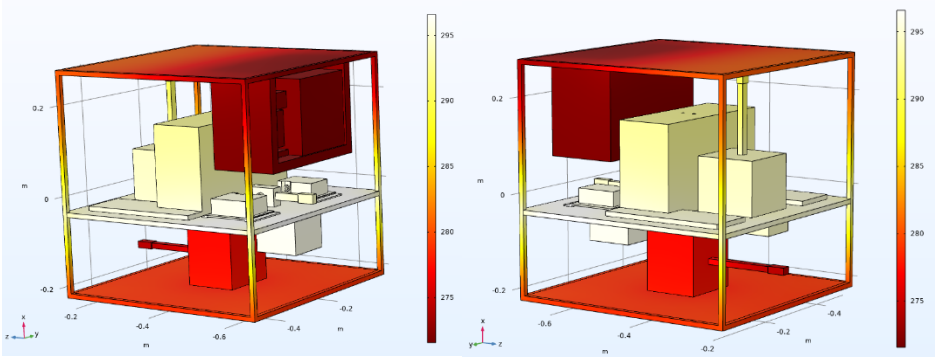


Figure.14 COMSOL analysis of satellite

The heater will be positioned in three locations: on the top and bottom plates, as well as on both sides of the middle plate. Controlled by a computer, the heater can deliver up to 0.4 W per cm², allowing for precise regulation of the operational temperature of all equipment.

2.5 Full structure design

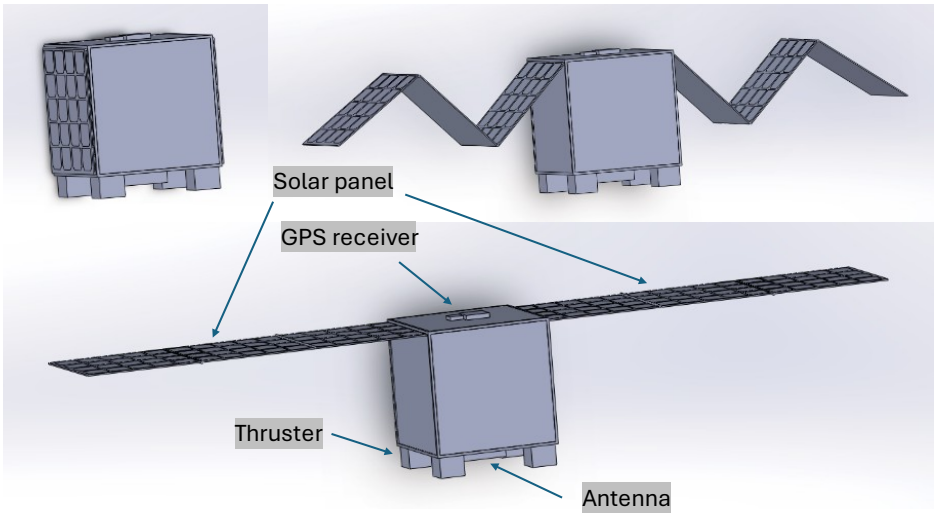
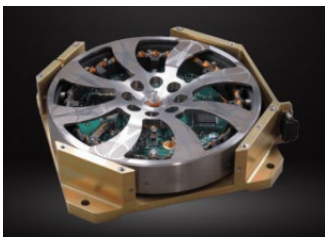
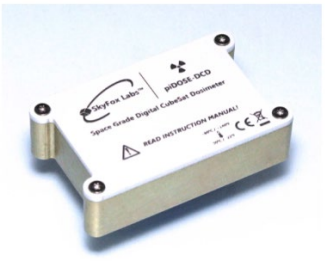


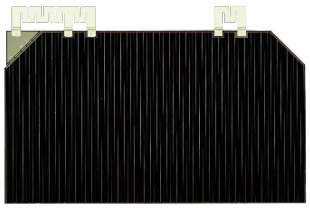
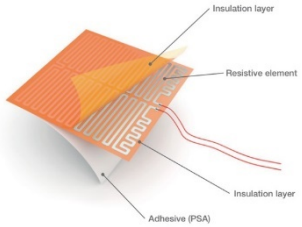
Figure.15 Develop of the solar panel

The full structure design will compose the main structure with the solar panel and the communication system, all the detailed instrument is listed in the table of instruments, including the attitude control, data acquisition, and power supply.

Once the satellite is sent to the target orbit, we can start the cultivation cycle of the microalgae, under the control of the automated system. The automated system should meet the requirements of the mission, and the operation temperature should be proper for the orbital environment. The following table is the instrument list of our satellite structure design.

Table.12 Satellite instrument

Satellite instrument			
Battery 4S1P VES16	700 g	-20 to 40°C	
	Saft	14.8V/66.6Wh	
Computer The ISIS On Board computer	100g	-25 to 65°C	
	Innovative Solutions In Space	3.3V/0.4W	
Reaction Wheel 1 Nms RW-1.0	1380g	-40 to 70°C	
	Rocket Lab	1.0 Nms ±100 mNm torque 28V/43W	
Thruster IFM NANO	900g	-20 to 40°C	
	ENPULSION	350 µN 12V, 28V 8 to 40W 3.5W (standby)	
Scintillator-type detector piDOSE-DCD	32g	-30 to 60°C	
	SkyFox Labs s.r.o.	0.2 to 10MeV 0.01 to 999.99µT 40µSv/h 5V/70mW	
Antenna FRONTIER -X	920g	-25 to 55°C	
	Rocket Lab	Receive 7145 to 7235 MHz 30V/12W Rx+Tx	
		Downlink 10 Bd to 13.3 MBd	

		1.7 bps to 13.3 Mbps Uplink 10 Bd to 1 MBd 8.8 bps to 1.8 Mbps	
Solar cell ZTJ+	150mg/cm²	Any temperature	
	Rocket Lab	39.79 mW/cm² Vmp 2.39V Jmp 16.65mA/cm² Environment 1-MeV, 1E15 e-/cm² P/Po is 0.87	
GPS Receiver GEMINI-SR5 GEMINI-A01	200g	-10 to 50℃	
	NEWSPACE SYSTEM	1575.42 MHz RS-422 /TTL UART 5V/2W	
Heater SPFHE	50mg/cm²	-65 to 150℃	
	Zoppas Industries	28V/0.4W per cm²	
		Insulation Material: Polyimide + Acrylic	
Multilayer Insulation Kapton® Film	0.5g/cm³	-250 to 290℃	
	Dunmore Aerospace	Outside α/ϵ : 3.5 Inside α/ϵ : 0.63 Withstand extreme temperature Radiation resistance Minimize heat flow	

With the requirement of the satellite mission, the equipment should be under the characteristics such as resistance to the varied environment, the data transaction need, and the control of the systems on the satellite.

For the varied environment, we choose the heater that can be controlled by the computer. The heater can provide up to 0.4W per cm² that will be attached to the wall plate of the satellite, and by the multilayer insulation material, it can protect the satellite from the burn of space radiation and keep the operational temperature. The Scintillator-type detector is also applied on the satellite that is used

as a monitor to measure the beta ray that has a massive impact on our cultivation of the microalgae, which is also decided by the total ionization dose the biomass received.

For the data transaction need, we need to send the data of the text file of the description of the database from the sensors and spectrometer, as well as the photo taken by the camera. The designated data transaction amount would be below 5MB per downlink to the ground station in each return. The orbit of our satellite would be a polar LEO orbit inside the inner Van-Allen belt, so the equipment we would like to choose for the data transaction is that it can be transferred through the atmosphere and sufficient for our data scale. So, we chose the X-band antenna that is suitable for our data amount.

For system control, we need the GPS receiver and reaction wheel controlled by the computer for height and attitude control, by using the GPS to know where our satellite is, we can use the thruster and reaction wheel to adjust the attitude and position of the satellite. The system energy budget is provided by the solar panel and the battery, we use two batteries to make sure the power budget is enough even in the extreme mode, we designed the solar panel to be foldable, so we can choose to expand one, two, or three panels for the energy consumption depends on the situation.

By choosing these equipment, the system operation would be under control under the varied environment we want to place our satellite. With the support of such devices, the cultivation of the microalgae under the space radiation environment could be operated appropriately and may be self-sustained.

3. Mission Mode

As mentioned in the previous sections, our mission's purpose is to test the capability of microalgae in processing human waste in space. The key to this is the cultivation of microalgae, which is an important technology. Moreover, we are not manually cultivating the microalgae; instead, we are using machinery to semi-automatically cultivate them within the satellite's internal space. Therefore, we must understand all the conditions necessary for cultivating microalgae, with the selection of the medium and the control of environmental conditions being the most crucial factors.

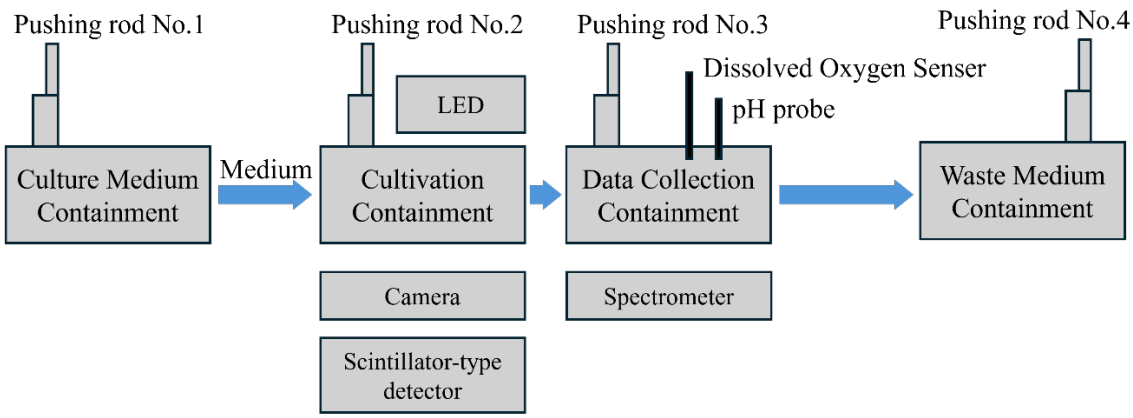


Figure.16 Mission payload

3.1 Environmental Conditions

Before starting the cultivation, we need to determine the environmental conditions for growing microalgae. All biological cultures have specific environmental requirements, such as temperature, light intensity, and light cycles, and *Chlorella vulgaris* is no exception. To ensure the successful growth of *Chlorella vulgaris* in space, we reviewed the literature and found that the optimal growth conditions are 22 ± 2 °C, 3000 LUX, and a 16:8 light-dark cycle (Fig17). However, since we aim for a longer growth period to allow more time to observe the growth curve, we concluded, after consulting with laboratories experienced in cultivating microalgae, that the best conditions are 18°C, 3000 LUX, and a 16:8 light-dark cycle.

3.2 Medium

Initially, we considered using urine as a medium. However, to avoid contamination of the instruments by microorganisms present in the urine and to ensure that the microalgae are not contaminated during the cultivation process, we decided to use urea and other components for the experiment. The medium we selected for our experiment is BG-11 medium, but we have adjusted the nitrogen source components based on the goal of our experiment. We will use urea as a nitrogen source to simulate the processing of human waste by microalgae. The components of the medium are summarized in Table.13.

Table.13 Component of medium（pH5.5）

Component	Final Concentration(mg/L)
Urea	530
$MgSO_4$	36.6
K_2HPO_4	30.5
$CaCl_2·2H_2O$	27.2
Na_2CO_3	100
Citric acid	6
Ferric ammonium citrate	6
Sodium EDTA	1
H_3BO_3	2.86
$MnCl_2·4H_2O$	1.81
$Na_2MoO_4·2H_2O$	0.39
$ZnSO_4·7H_2O$	0.222
$CuSO_4·5H_2O$	0.079
$Co(NO_3)_2·6H_2O$	0.0409

Based on the mission phases, after the satellite is launched into orbit, our mission is divided into three cyclical phases, including the Cultivation phase, Measurement phase, and Subculture phase Fig17. These three phases will be repeated until ten cycles of microalgae subculture are completed.

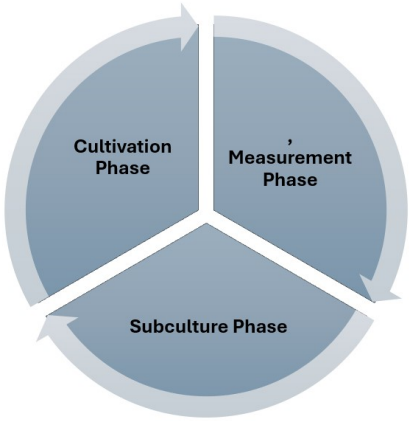


Figure.17 Phase cycle

3.3 Cultivation Phase

In this mission, once the satellite reaches the target orbit set for our mission, we will begin the experiment. The first step in our plan is the cultivation of *Chlorella vulgaris*. Our experimental setup includes a microalgae cultivation tank and a culture medium storage tank. We will use a motor to pump the culture medium from the storage tank to the microalgae cultivation tank, where the *Chlorella vulgaris* inoculum will be cultured.

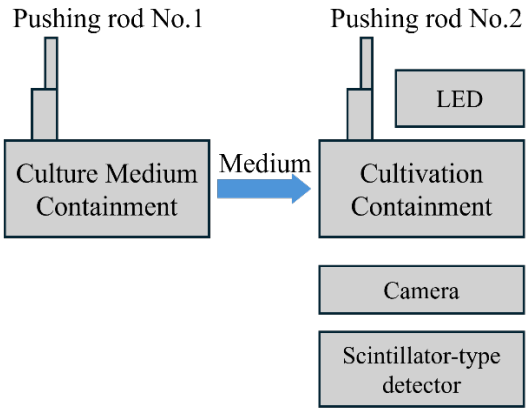


Figure.18 Cultivation phase

3.4 Measurement Phase

To monitor the changes occurring during the cultivation of microalgae, we will simultaneously perform data measurements while cultivating *Chlorella vulgaris*. These measurements include pH value, dissolved oxygen levels, OD, and photographs. According to our 16:8 light-dark cycle, we aim to collect data during the light cycle of the microalgae, with measurements taken twice daily. Therefore, we divide the 24-hour data cycle into a 12-hour light cycle and an 8-hour dark cycle plus a 4-hour light cycle (12+8:4). This data allows us to monitor the growth of *Chlorella vulgaris*, create growth curves, and provide reliable evidence for our cultivation results.

During this process, we will first use a dissolved oxygen (DO) meter to measure the dissolved oxygen levels in the cultivation tank. Dissolved oxygen refers to the concentration of oxygen dissolved in water. Measuring DO serves to monitor water quality. It is well known that microalgae can produce oxygen through photosynthesis, so measuring DO can indirectly monitor the efficiency of photosynthesis and allow us to assess the cultivation conditions of the microalgae.

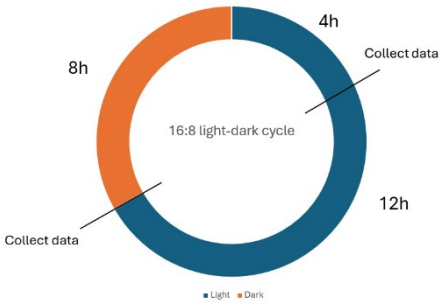


Figure.19 Light cycle

A pH sensor will be used to detect changes in the pH value within the cultivation tank. Since all organisms have a unique pH range for optimal growth, measuring the pH value changes can monitor growth rates during that period. The growth curve serves as a reference, providing reliable evidence for the results of microalgae cultivation. (6)

We will measure the concentration of microalgae in the cultivation medium using the following method. A motor will pump the medium from the Cultivation Tank to the Measurement Box. A 680 nm LED will pass light through the Measurement Box, which will then be detected by the Detector. Afterward, the medium will be pumped back to the cultivation tank. The data obtained will be used to calculate the growth concentration of the microalgae and create a growth curve. To ensure the accuracy of the data, a camera will be used for simple visual observation.

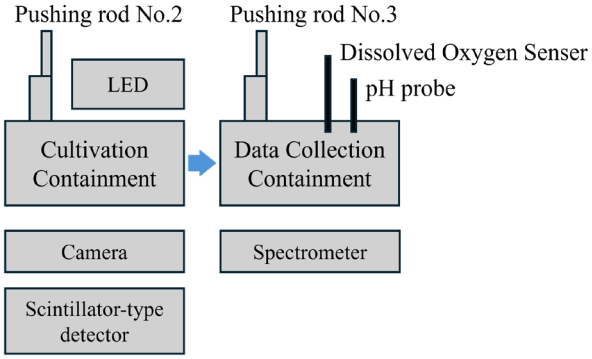


Figure.20 Measurement phase

3.5 Subculture Phase

When *Chlorella vulgaris* reaches the logarithmic growth phase, we will begin the Subculture Phase. We can determine the timing for subculturing based on the received data. When the returned data shows that the measured OD value reaches 0.5, we will start the next generation of *Chlorella vulgaris* cultivation. Thus, our Mission Phase returns to the Cultivation Phase, repeating the cycle continuously.

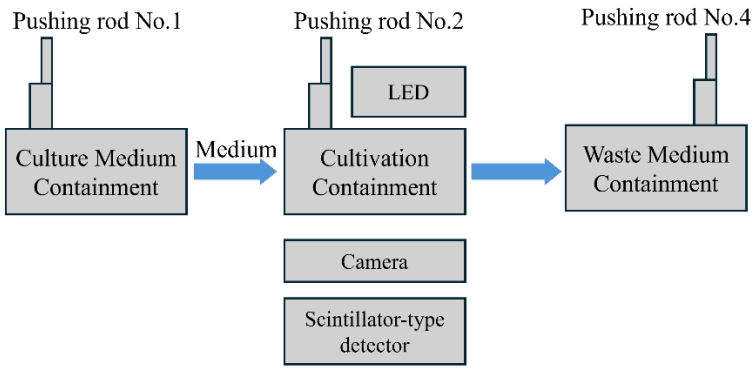


Figure.21 Subculture phase

4. Control System

4.1 Attitude control

Mass	45.842kg		
Centre of mass		The main axis of inertia	Principal moment of inertia
X	-24.99mm	lx (0.04, -0.34, 0.94)	Px = 1.4 $kg \cdot m^2$
Y	3.17mm	ly (0.16, -0.93, -0.34)	Py = 1.92 $kg \cdot m^2$
Z	8.25mm	lz (0.99, 0.17, 0.01)	Pz = 1.99 $kg \cdot m^2$

I. Thruster

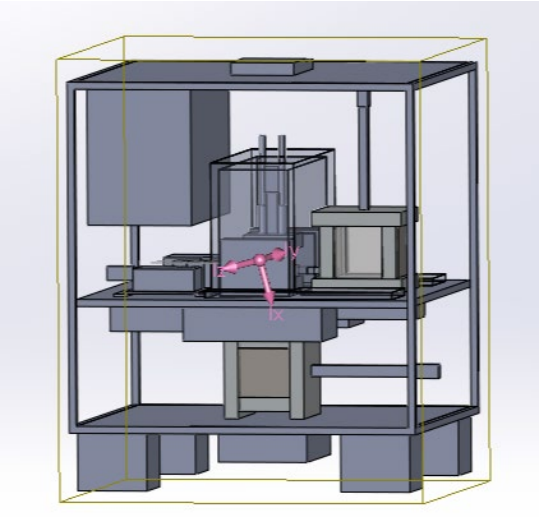


Figure.22 Satellite full design

Since GENESIS does not require long-duration space travel or orbital altitude changes, it does not need a large propulsion system. Instead, GENESIS relies on precise and minute attitude control. Therefore, a thruster on Field Emission Electric Propulsion(FEEP) technology, IFM Nano Thruster, is used for GENESIS. FEEP is an efficient electric propulsion technology primarily used for attitude control and orbit adjustment of microsatellites and nanosatellites. FEEP thrusters generate thrust by emitting ions using an electric field, featuring high specific impulse and precise thrust control. FEEP thrusters typically use liquid metals as propellants, such as cesium (Cs), indium (In), or gallium (Ga). These metals have low vapor pressures at room temperature, making them suitable as ion sources. The operational principle involves heating the propellant and delivering it to the tip of an emitter via capillary action. Under a strong electric field, the liquid metal surface forms a Taylor cone, from which metal ions are emitted at the tip. These emitted metal ions are accelerated by the electric field, passing through the thruster's acceleration electrodes and reaching high velocities, thus generating thrust. The accelerated ions are expelled through a nozzle, creating a reactive force that propels the satellite. The magnitude of the thrust can be precisely controlled by adjusting the electric field strength and the propellant flow rate.

There are 4 same thrusters applied at the four corners of the bottom of the satellite, and then cooperate with 1 reaction wheel to conduct the 3-axis attitude control.

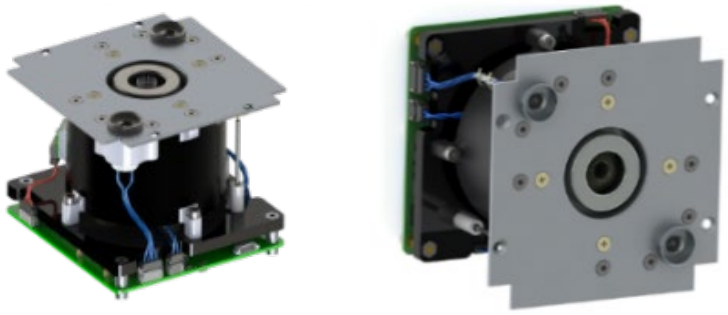


Figure.23 Thruster (IFM NANO THRUSTER)

II. Reaction Wheel

The operating principle of a reaction wheel is based on the law of conservation of angular momentum, controlling the attitude of a spacecraft by changing its rotational speed. The law of conservation of angular momentum states that in the absence of external torques, the total angular momentum of a system remains constant. For a system consisting of a spacecraft and reaction wheels, the sum of the angular momentum of the spacecraft and the reaction wheels is constant. When attitude adjustment is required, the reaction wheel is accelerated or decelerated by an electric motor. Changes in the rotation speed of the reaction wheel cause changes in its angular momentum. For example, if a reaction wheel accelerates clockwise, its angular momentum increases, causing the spacecraft to rotate counterclockwise to maintain the total angular momentum constant. By precisely controlling the rotational speed of the reaction wheel, the spacecraft can achieve accurate attitude adjustments. This control method is particularly suitable for tasks requiring high-precision attitude control, such as satellite imaging, scientific observation, and communication alignment. Reaction wheels offer advantages such as high-precision attitude control, electric drive without fuel consumption, quick response, and suitability for various complex attitude adjustment needs.

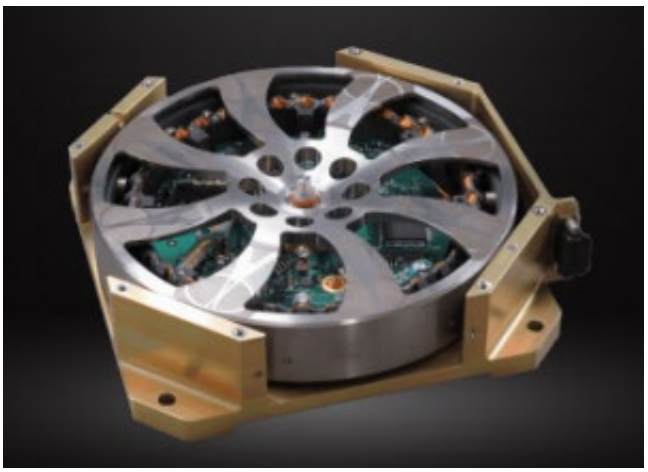


Figure.23 Reaction wheel (RW-1.0)

The 1 Nms RW-1.0 reaction wheel from Rocket Lab is used in GENESIS.

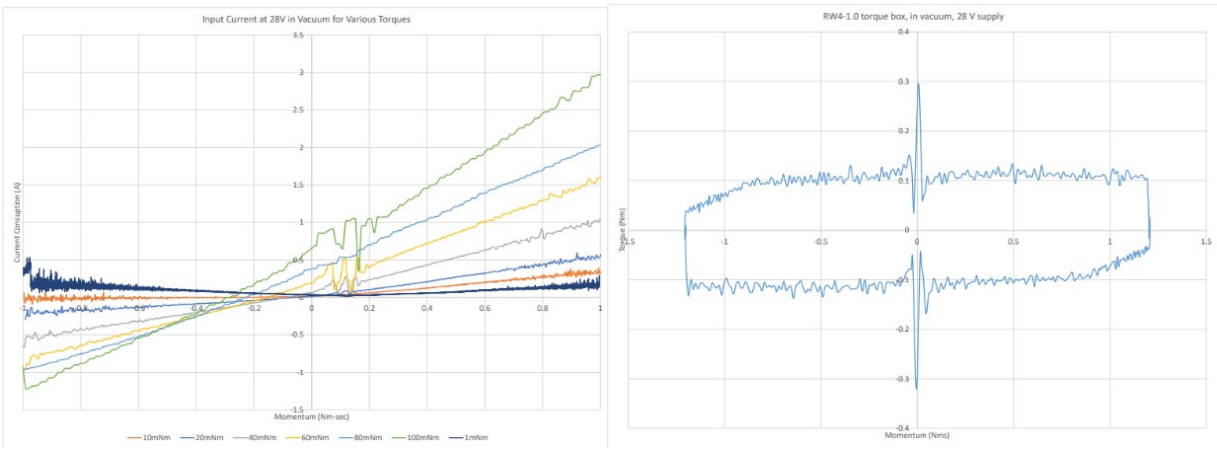


Figure.24 Profile of the reaction wheel

4.2 Thermal Control

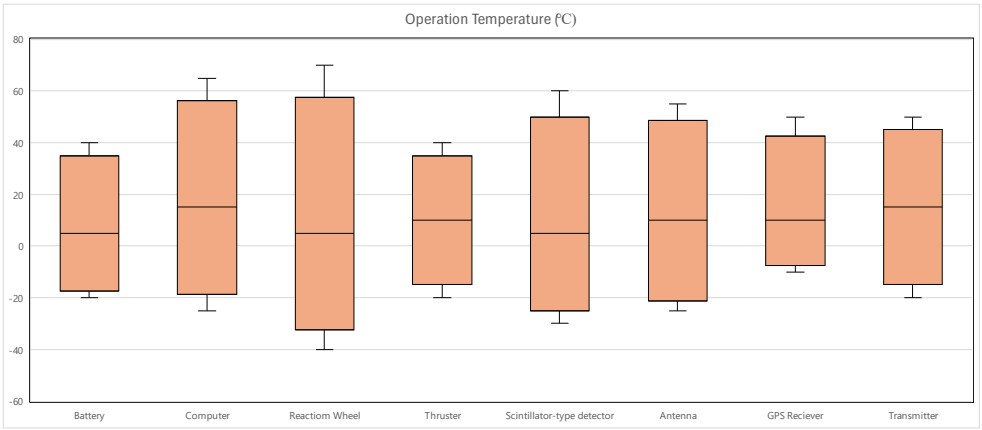


Figure.25 Operation temperature of the instrument

Considering the operation temperature of the instruments installed on the satellite, we will maintain the satellite at an appropriate temperature that should be proper for the instrument and microalgae growth. In the graph, the operation temperature can be workable for all the instruments is 10 to 30℃, and the best temperature for microalgae to grow is 18℃, so the thermal control is acceptable for us to control the temperature of the satellite at 18℃± 2℃.

4.3 Energy Budget

Table.14 Energy budget of each instruments

Subsystem	**Instrument**	**Power Consumption (W)**	**Launch mode**	**Booting Mode**	**Detumbling mode**	**Propulsion mode**
ADCS	Reaction wheel	5.3	off	off	on	on
	IMU	2.2	off	off	on	on

	Sun/Star Tracker	4	off	off	on	on
	GPS receiver	2	off	off	on	on
	IFM NANO THRUSTER	160	off	off	off	on
TT&C	Transmitter (X band)	5	off	on	on	on
	Receiver (X band)	7	off	on	on	on
C&DH	ISIS	0.4	off	on	on	on
PAYLOAD	LED	12	off	off	off	off
	Micro camara	1.25	off	off	off	off
	Dissolved Oxygen sensor	0.85	off	off	off	off
	pH probe	1	off	off	off	off
	Scintillator-type detector	1	off	off	off	off
	Spectrometer	10	off	off	off	off
	Pushing rods	5W*4	off	off	off	off
TCS (MAX)			0	237.5	237.5	237.5
Total (W)			0	249.9	263.4	423.4

Subsystem	**Instrument**	**Power Consumption (W)**	**Experiment mode**		
			Cultivation mode	**Subculturing mode**	**measurement mode**
ADCS	Reaction wheel	5.3	on	on	on
	IMU	2.2	on	on	on
	Sun/Star Tracker	4	on	on	on
	GPS receiver	2	on	on	on
	IFM NANO THRUSTER	160	on	on	on
TT&C	Transmitter (X band)	5	on	on	on
	Receiver (X band)	7	on	on	on
C&DH	ISIS	0.4	on	on	on
PAYLOAD	LED	12	on	on	on
	Micro	1.25	on	on	on

	camara				
	Dissolved Oxygen sensor	0.85	off	off	on
	pH probe	1	off	off	on
	Scintillator-type detector	1	on	on	on
	Spectrometer	10	off	off	on
	Pushing rods	5W*4	on	on	on
TCS (MAX)			237.5	237.5	237.5
Total (W)			442.65	447.65	449.5

For the energy consumption of all the instruments in the count, we should have a proper power supply that can fulfill the situation that is enough if all the instruments work all at once. The energy budget relies on the power supply and storage from batteries and solar panels, through our calculation, the energy supply is sufficient for the instrument to use and can even be more to charge the batteries.

In the usual conditions, we will not make every instrument work all the time, the system will make most of our power used in maintaining the system operation, and the duration of operating the instrument is short, to acquire the data and do the subculture, so the power budget is reliable.

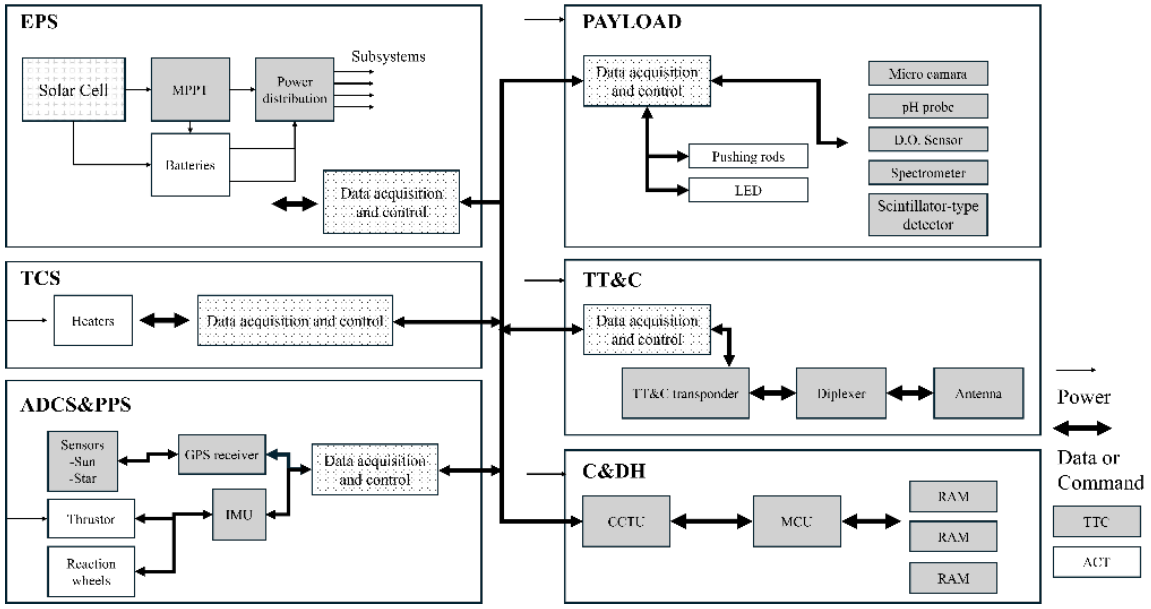


Figure.26 Block diagram of the electrical system and data system

4.4 Communication

type	contents	Data (bites)	Sensor number	Total data (bits)
position	GPS	32	1	32

	velocity	16	3	48
attitude	Sun sensor	16	1	16
	RW	8	1	8
	Angle	16	3	48
	Angular velocity	16	3	48
Power system	Power generation	32	2	64
	battery	16	2	32
	PCDU	8	2	16
other	time	32	1	32
	temperature	8	1	8
	Error checking	16	1	16
TOTAL				368

HK data rate is 368 bps which is about 31.8 Mb a day.

X band antenna and ground station receiver, a downlink speed of 1.8 Mbps is possible, with an access time of 3000s per day, resulting in a maximum data transfer of 5.4 Gb per 24 hours. While the maximum mission data per day is 50 Mb, leaving plenty of room for improvement.

5. Originality and Social Effect

The mission of GENESIS is the first fully automated, multi-generational cultivation mission for microalgae. This mission aims to revolutionize the handling of vital human metabolites during long-term space travel and provide a continuous nutritional source for space food, significantly contributing to the increasingly prevalent field of space travel. Furthermore, the mission of GENESIS spans both aerospace engineering and biological sciences, adopting an interdisciplinary approach to encourage future academic and industrial collaboration across various fields with aerospace engineering.

This will pave the way for more innovative interdisciplinary space missions, marking a significant advancement in the history of human space exploration.

6. Expected spent

Components	Estimated cost (USD)	Components	Estimated cost (USD)
Structure	30000	GPS Receiver	3200
Computer	12000	Antenna	3200
Battery(EPS)	35000	Camera	2000
Transmitter	25000	Probe	2000
Thruster	42000	Geiger Counter	1500
Reaction Wheel	35000	Spectrum System	3000
Solar Panel	30000	Total	223900

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Question & Answer Form

Satellite Design Contest

1. We want the design report to include a table of contents.

Reply:

Thanks for the reviewers' comments and kindly reminder, we have added a table of contents in the first page of the support document.

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2. It might be requested to argue the scientific significance of exposing Chlorella in a high space radiation environment (inclination 78 deg., and 7,200 km alt. orbit) while aiming to develop a life support system for human-crewed space missions. Humans cannot withstand such harsh environments. The radiation resistance of Chlorella can be examined in detail on the ground. Issues that should be verified in space include how the repair processes affected by radiation exposure in a microgravity environment differ and how the risks of exposure to space-specific high-energy heavy particles differ from ordinary radiation experienced on Earth. The experimental design does not allow for clarification of these matters. If we want to evaluate genetic stability in space radiation exposure, recovering biological samples on Earth will be necessary. Although it appears that Chlorella will be cultured in 40 ml and cell density will be observed, there are significant scale effects involved in

rearing living organisms. It is essential to conduct preliminary experiments to confirm whether meaningful results can be obtained in this culture volume. A description of how to manage media and measure/control carbon dioxide and other factors needs to be provided. Some aspects of sensor selection require detailed consideration. For spectrometric monitoring of culture medium, measuring the intensity of specific bands may be sufficient instead of spectra analyzed with a spectrometer. A glass electrode has been selected for the DO sensor, but it would be better to choose a sensor suitable for space experiments. For pH measurement, it is advisable to consider ISFET-type sensors rather than electrochemical glass electrodes. Scintillator-type detectors should be considered instead of a Geiger counter for beta radiation detection. An ammonia sensor also needs to be evaluated. The development phases for biological payloads should carefully consider their characteristics. The design of radiation resistance for systems composed of electronic devices and the verification of its effectiveness is also important. It should be noted that there is dose rate dependency in the effects of exposure on organisms (involving repair processes), and it is not feasible to conduct accelerated tests on the effects of total exposure at high dose rate conditions.

Reply:

Thanks for the reviewers' comments and valuable suggestions.

Our mission aims to develop life support systems for human-crewed space missions. In our project, Chlorella vulgaris is key to handling human-generated waste. The scientific significance of exposing Chlorella vulgaris in this high-altitude radiation environment lies in providing a reference for developing ecological recycling systems in space exploration. Future space exploration missions, such as Mars exploration or long-term space habitation, will require sustainable ecological recycling systems. Due to its high carbon dioxide fixation ability and oxygen release characteristics, Chlorella vulgaris is considered a potential candidate organism. Researching its behavior in high-radiation environments can help design more resilient and sustainable ecological systems to support long-term space missions. Our mission can also lay a foundation for subsequent studies on Chlorella vulgaris in space. Therefore, we aim to observe the growth of Chlorella vulgaris in this high-altitude radiation environment. Based on our research, the radiation resistance of Chlorella vulgaris is sufficient to withstand the radiation dose at this altitude. Although its growth rate may be suppressed, the radiation level at this altitude does not cause microalgae to die from excessive radiation accumulation during the cultivation process, nor does it lead to immediate death.

Regarding microgravity and radiation, our research suggests that exposing

Chlorella vulgaris to a microgravity radiation environment affects its cell repair. In terms of outcomes, the growth rate of Chlorella vulgaris decreases. For example, gamma rays have a biological impact on cell components, particularly water molecules. Gamma rays interact with the growth medium, generating free radicals, which can alter cell composition. However, under the radiation dose we anticipate, cells may experience slight damage, but the repair process functions normally. Additionally, protein synthesis decreases with increasing radiation dose, which may lead to enhanced photoinhibition of photosynthesis, thereby inhibiting the growth rate of Chlorella vulgaris. Space has radiation with higher energy and greater penetration than on Earth. When Chlorella vulgaris is exposed and cultured at the target altitude, it is more susceptible to radiation effects, such as increased cellular and genetic mutations. We aim to expose Chlorella vulgaris to high-energy particles unique to space, which aligns with our mission objectives, and we have confirmed that Chlorella vulgaris can survive in this environment, allowing us to obtain meaningful research results. We do not plan to retrieve biological samples on Earth as we believe gene stability issues will be reflected in the growth rate of Chlorella vulgaris. Therefore, our project will produce absorbance data, which will help us create a growth curve for the microalgae culture and calculate its growth rate using the formula: $\mu=(\ln(OD2)-\ln(OD1))/(t2-t1)$

OD1 and OD2 are the absorbance values measured at times t1 and t2, respectively, with $t2-t1$ as the interval between measurements.

Regarding scaling, while the culture volume could be increased, we chose a 40ml culture volume due to satellite size limitations. This also proves that if we successfully cultivate in a 40ml volume, larger volumes of 400ml or more can be cultivated smoothly. We consulted a university laboratory that conducts microalgae research to conduct preliminary experiments to ensure feasibility.

The actual culture process is as follows:

Since the lab could not provide Chlorella vulgaris for our experiment, we used Chlorella sorokiniana in the preliminary experiment, as the lab has more experience culturing this species. Chlorella sorokiniana is similar to Chlorella vulgaris, but it thrives better in a higher temperature range and is more suitable for large-scale culture; other effects and culture methods are the same as those for Chlorella vulgaris. Thus, we determined it was feasible to use this species in the preliminary experiment. We placed an initial OD value of 0.05 of algae in a 40ml container and left it at 28˚C in a static and non-aerated environment, and the results showed successful cultivation in this volume (data provided by Professor I-Son Ng's lab at National Cheng Kung University), with meaningful pH and absorbance data obtained.

The management of the culture medium is crucial to our project. We will use various sensors to collect culture data, with a primary focus on monitoring pH changes. PH variations provide us with valuable information, such as insights into carbon dioxide control. Instead of using the traditional BG-11 medium, we replaced its nitrogen source with urea. During cultivation, this medium releases ammonia and carbon dioxide, the latter of which will be fixed by Chlorella vulgaris. We anticipate that ammonia will gradually raise the pH of the culture medium during cultivation, and the preliminary experiment confirmed our hypothesis. In actual space cultivation, since we will transfer Chlorella vulgaris to the measurement box and waste tank to supplement fresh culture medium, we predict that pH fluctuations will have minimal impact on the overall culture process. However, as a precaution, when sensors detect that the pH of the culture medium exceeds a certain threshold or if we observe anomalies in the data, we will have a manual or automated method in place to replenish the medium and stabilize its pH level.

Regarding sensor selection, we are grateful for the reviewers' suggestions. First, we decided to remove the ammonia sensor. Initially, we intended to monitor the use of urea by Chlorella vulgaris, but many studies have already demonstrated the feasibility of cultivating Chlorella vulgaris with urea, so we decided to omit the ammonia sensor. For the other sensors, after consulting relevant information, we decided to follow the reviewer's recommendations. We will use the principle of spectrophotometry, with OD680 as our measurement wavelength. The DO (dissolved oxygen) sensor will employ a Digital Dissolved Oxygen Meter, and for pH measurement, we will use an ISFET-type sensor as suggested. In our research, we found that Geiger counters may encounter issues with detection accuracy. In contrast, scintillation detectors can record instantaneous data over short periods and integrate the data over a set duration, making them an active sensing component. The scintillation detector we selected not only detects the beta radiation mentioned by the reviewers but also provides the Total Ionizing Dose (TID) for space radiation, which serves as a reference for biological cumulative radiation exposure (the radiation resistance of our electronic equipment has been confirmed). Thus, we have decided to switch to this detector as per the reviewers' recommendation.

3. You state that the reason for selecting a polar orbit with an orbital inclination of 78 degrees and SMA of 7199.9 km is to maintain a radiation environment for the payload, but please provide evidence that this orbit will satisfy the mission requirements. What kind of launcher do you envision as the means to inject the payload into this orbit? Is this a realistic launcher? Please describe to the extent that it is reasonable to do so.

Reply:

Thanks for the reviewers' question.

Our mission is to put the microalgae in an environment with high radiation(we will focus on gamma rays) and see what will happen to the microalgae. We look forward to getting some results that can help in future space missions.

We choose the orbit so that it will pass through a high-latitude area that overlaps with radiation belts and polar areas. In such an environment, the satellite will be exposed to higher cosmic rays, including gamma rays, which will provide the necessary conditions for studying the radiation tolerance of microalgae. To not kill the microalgae, we use SPENVIS to ensure the cumulative dose will not exceed 1000Gy(this dose may kill the microalgae from knowing paper), and the orbit will pass through a fixed station about 15 times a day; we will have lots of time to get the data because we need to record and collect the data at least once a day.

rocket	H-II	H-IIA With Castor 4A-XL	H3
Height(m)	49	53	63
Diameter(m)	4	4	5.27
Mass(kg)	260000	285000-445000	574000
Stages	2	2	2
Payload to LEO (kg)	10060	10000-15000	16500
Maximum thrust(Kn)	First:1077.996 Second:121.5 Booster:1540	First:1098 Second:137 Booster:765	First:2944/4416 Second:137 Booster:4316/8632
Specific impulse(s)	First:446 Second:452 Booster:273	First:440 Second:447 Booster:282.6	First:425 Second:448 Booster:283.6
Booster Burn time(s)	94	58	105

We chose H-II because the specific impulse is the highest. The specific impulse is the efficiency of the rocket engine. $I_{sp} = \frac{F_{thrust}}{\dot{m} \times g_0}$. Therefore, the rocket H-II is the most efficient and suitable launcher for us.

4. The solar panels are quite large, but have you considered a folding mechanism, a latching method at launch, and a deployment method in orbit? If so, please describe the method.

Reply:

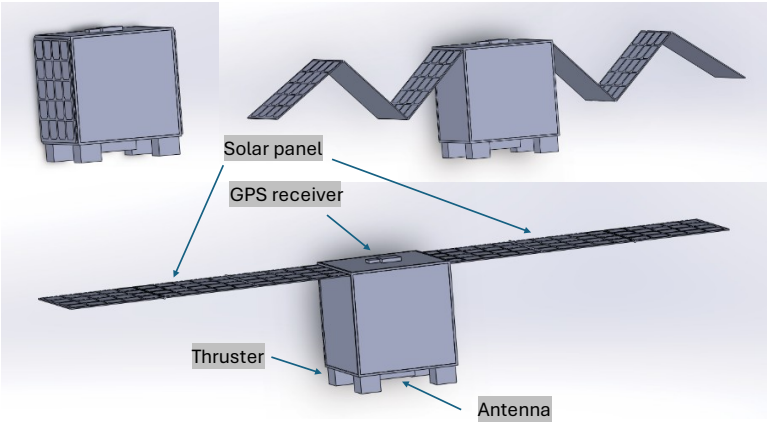
Thanks for the reviewers' questions and reminders.

Yes, we took the folding mechanism into consideration for our design.

Our structure design will be operated with a shaft that can pack the solar panels up, and the thickness of our solar panels is very thin. By this design, we can fold it firmly on the surface of the satellite, and by this, we can minimize the impact of the size of the solar panel before latching.

After the satellite is sent to the desired orbit, we may expand the wings of the solar panel by the shaft, and we designed three sub-panels controlled by the shaft. By this, we can choose, depending on the situation, to open it in one-panel size, two-panel size, or full-panel size. This may be helpful because attitude control will be hard if the momentum of the satellite is too large. With a smaller size, we can have better control of the attitude and direction of the satellite.

The solar panel provides 39.79 mW/cm² of energy production, so the maximum energy consumption provided by the solar panel would be 359W, which is suitable for our satellite design.



5. A list of components is provided, but the basis for the selection of each needs to be clarified, and these need to be in compliance with the system requirements to achieve the mission requirements. Please provide the rationale for equipment selection or show that the equipment satisfies the system requirements.

Reply:

Thanks for the reviewer's question.

With the requirement of the satellite mission, the equipment should be under the characteristics such as resistance to the varied environment, the data transaction need, and the control of the systems on the satellite.

For the varied environment, we choose the heater that can be controlled by the computer. The heater can provide up to 0.4W per cm^2 that will be attached to the wall plate of the satellite, and by the multilayer insulation material, it can protect the satellite from the burn of space radiation and keep the operational temperature. The Scintillator-type detector is also applied on the satellite that is used as a monitor to measure the beta ray that has a massive impact on our cultivation of the microalgae, which is also decided by the total ionization dose the biomass received.

For the data transaction, we need to send the data from the text file describing the database from the sensors and spectrometer, as well as the photo taken by the camera. The designated data transaction amount would be below 5MB per downlink to the ground station in each return. The orbit of our satellite would be a polar LEO orbit inside the inner Van-Allen belt, so the equipment we would like to choose for the data transaction is that it can be transferred through the atmosphere and sufficient for our data scale. So, we chose the X-band antenna that is suitable for our data amount.

For system control, we need the GPS receiver and reaction wheel controlled by the computer for height and attitude control; by using the GPS to know where our satellite is, we can use the thruster and reaction wheel to adjust the attitude and position of the satellite. The system energy budget is provided by the solar panel and the battery. We use two batteries to make sure the power budget is enough even in the extreme mode; we designed the solar panel to be foldable, so we can choose to expand one, two, or three panels for the energy consumption depending on the situation, and the size of the solar panel is acceptable.

By choosing this equipment, the system operation would be under control under the varied environments in which we want to place our satellite. With the support of such devices, the cultivation of microalgae in space radiation environments could be operated appropriately and self-sustaining.

6. Although a range of operating temperatures for the equipment is provided, it needs to be clarified from the results of the on-orbit thermal analysis that each piece of

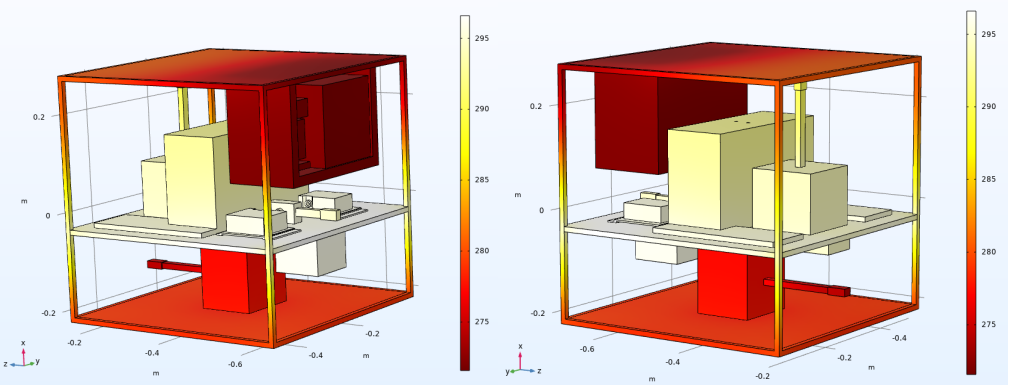
equipment is within the allowable temperatures. Where can I look to confirm these results?

Reply:

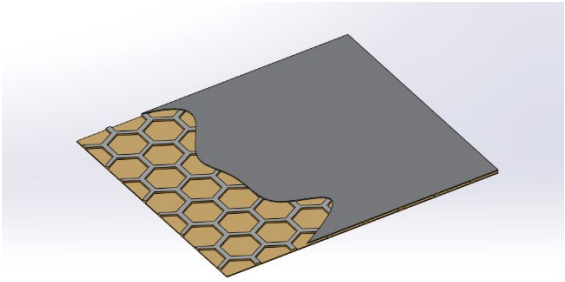
Thanks for the reviewers' questions and reminders.

The mission payload should be controlled under the operation temperature of the equipment. By doing the COMSOL simulation, the temperature distribution should be around 18℃ ± 2℃ for the microalgae cultivation, and the other equipment can be operated at around 0℃. This energy distribution should be suitable for our thermal control in the mission.

To simplify the simulation, this model ignored the too-detailed design and only focused on the operation equipment that can be impacted by the temperature.



We also designed the hexagonal aluminum plate design covered by the multilayer insulation material that can protect the cultivation of the microalgae from being directly burned by space radiation while maintaining the operation temperature in the satellite.



7. What is FEEP used for? Is it stationary keeping? Am I correct in understanding that attitude control is performed by RW? In this case, is RW 3-axis?

Reply:

Thanks for the reviewers' question.

Yes, FEEP is used for stationary keeping and attitude control. The RW is 1-axis, so we decided to increase the number of thrusters. We will put four thrusters at the four corners of the bottom of the satellite and then put 1-axis RW to accomplish 3-axis attitude control.

8. Table 6 needs to be clarified. After distinguishing between consumption and recharging, what kind of balance is achieved in each operation mode should be clearly described. In this case, indicate the maximum DOD of the battery cell.

Reply:

Subsystem	Instrument	Power Consumption (W)	Launch mode	Booting Mode	Detumbling mode	Propulsion mode	Experiment mode		
							Cultivation mode	Subculturing mode	measurement mode
ADCS	Reaction wheel	5.3	off	off	on	on	on	on	on
	IMU	2.2	off	off	on	on	on	on	on
	Sun/Star Tracker	4	off	off	on	on	on	on	on
	GPS receiver	2	off	off	on	on	on	on	on
	IFM NANO THRUSTER	160	off	off	off	on	on	on	on
TT&C	Transmitter (X band)	5	off	on	on	on	on	on	on
	Receiver (X band)	7	off	on	on	on	on	on	on
C&DH	ISIS	0.4	off	on	on	on	on	on	on
PAYLOAD	LED	12	off	off	off	off	on	on	on
	Micro camara	1.25	off	off	off	off	on	on	on
	Dissolved Oxygen sensor	0.85	off	off	off	off	off	off	on
	pH probe	1	off	off	off	off	off	off	on
	Scintillator-type detector	1	off	off	off	off	on	on	on
	Spectrometer	10	off	off	off	off	off	off	on
	Pushing rods	5W*4	off	off	off	off	on	on	on
TCS (MAX)			0	237.5	237.5	237.5	237.5	237.5	237.5
Total (W)			0	249.9	263.4	423.4	442.65	447.65	449.5

Thanks for the reviewer's comments.

We have redesigned the power consumption of the satellite and divided the system mode into more different situations, and under each mode, if the subsystems have the power consumption.

9. The feasibility of the communication system has not been confirmed. If line calculations have been performed, the results should be presented. Please also indicate the ground stations that are assumed to be operating stations.

Reply:

Thanks for the reviewers' comments.

We chose the Svalbard satellite station as the operating station where KSAT operates two polar ground stations optimized for low Earth orbit (LEO) satellites. This is the only one of two ground stations able to see a polar-orbiting satellite on every revolution. Since 2004, the Svalbard Undersea Cable System has provided two redundant fiber lines to the mainland, each providing 10 gigabits per second.

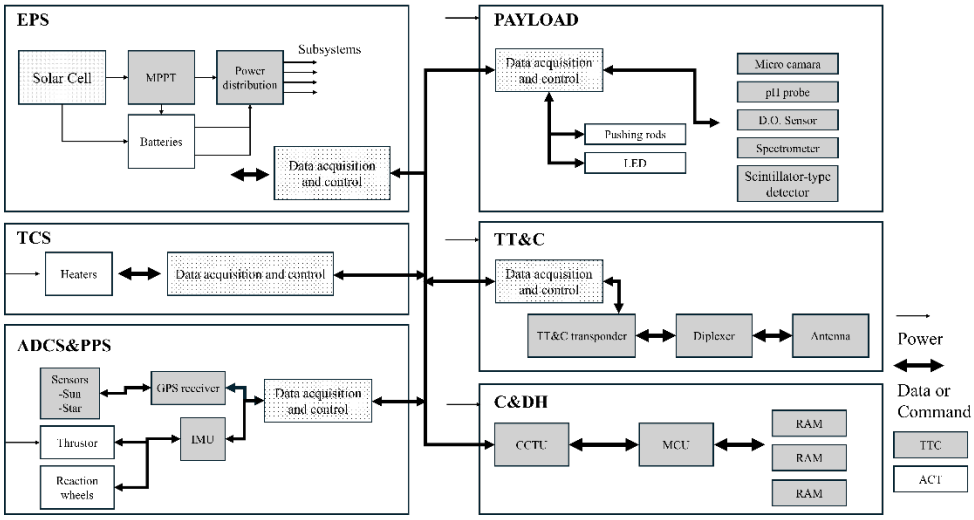
type	contents	Data (bites)	Sensor number	Total data (bites)
position	GPS	32	1	32
	velocity	16	3	48
attitude	Sun sensor	16	1	16
	RW	8	1	8
	Angle	16	3	48
	Angular velocity	16	3	48
Power system	Power generation	32	2	64
	battery	16	2	32
	PCDU	8	2	16
other	time	32	1	32
	temperature	8	1	8
	Error checking	16	1	16
TOTAL				368

HK data rate is 368 bps, which is about 31.8 Mb a day.

With an x-band antenna and ground station receiver, a downlink speed of 1.8 Mbps is possible, with an access time of 3000s per day, resulting in a maximum data transfer of 5.4 GB per 24 hours. While the maximum mission data per day is 50 Mb, leaving plenty of room for improvement.

10. There is no configuration chart of the entire system, weight distribution, or block diagram of the electrical system. These are important to show the feasibility of the system and should be included.

Reply:



We have finished a block diagram of the electrical system and combined the system

with the data transition system to clearly show the connections between the subsystems.