Report

GRUPO DE ESTUDIOS AEROESPACIALES

HaYuSat

CanSat France Competition 2025

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Project Code: CS01

September 2025

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1. About us

1.1 BIOMET-GEA

We are students from the Universidad Nacional de Ingeniería, located in Lima, Peru. With the growing interest in aerospace and space sciences, the GEA group was founded in 2022 by students from the BIOMET research group within our university Fig.1. To date, our work has focused on control theory, mechanical and electronic design, and simulations.

As a group, our goal is to innovate and promote space sciences through our participation in various international competitions, such as C'space, and in the publication of scientific articles.

Figure 1: photographs of Biomet members.

At Biomet, we are not only focused on the aerospace field, but we also have expertise in instrumentation, bioinorganic chemistry, and ecotoxicology. We have been working in these areas for over 5 years, forming a multidisciplinary group that includes students from Physics Engineering, Electrical Engineering, Mechanical Engineering, and Chemistry.

1.2 Team Organization and Roles

The group is composed of 6 members from the National University of Engineering, as shown in the following organizational chart. See Figure2.

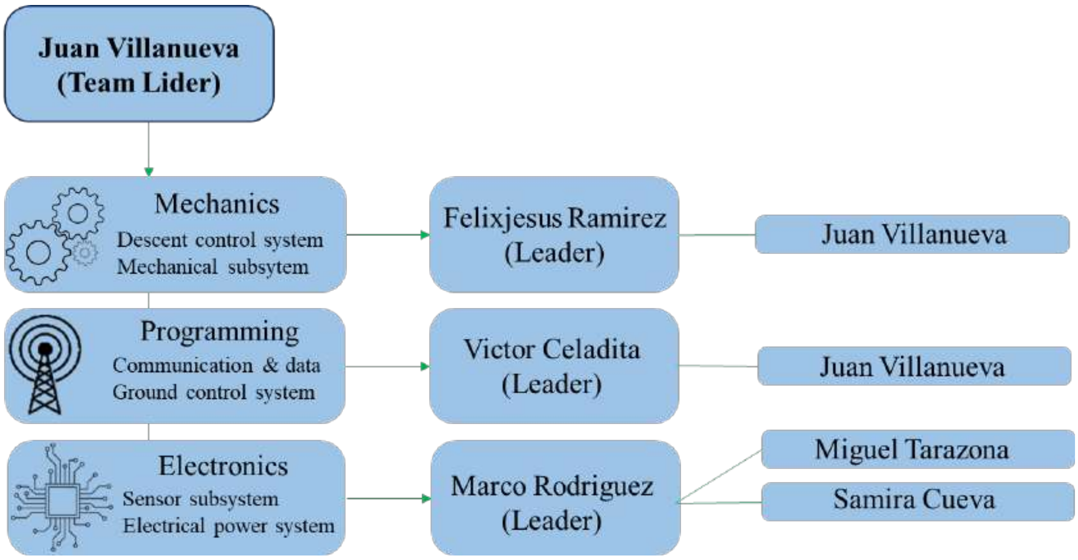


Figure 2: GEA team organizational chart

2. System overview

2.1 Missions

The HayuSat project chose the separation and transmission primary mission as its central focus. This consisted of splitting the CanSat into two parts at an altitude of between 40 and 60 meters and transmitting altitude and atmospheric variables data to the ground station in real time. Secondary missions included determining altitude without using barometric sensors or GPS, using alternative estimation methods, and measuring the distance between the two parts of the CanSat, with transmission of the results via telemetry. Finally, an additional mission was chosen to measure vibration during the fall using a piezoelectric sensor.

2.2 Electrical and Electronic System

Because the general structure will be divided into 2 parts, each of them must have an electronic system for the activities to be carried out, due to this the distribution was made as shown in Figure 3.

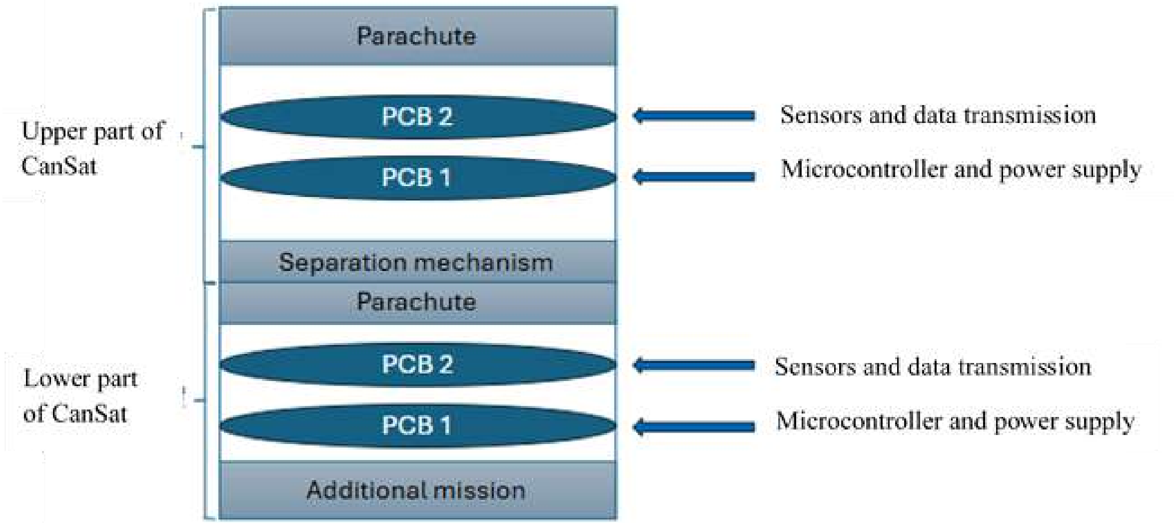


Figure 3: Distribution of PCBs.

2.3 Upper part of the CanSat

2.3.1 PCB1:

This circuit (Figure 5a), implemented on a PCB, is based on a Raspberry Pi Pico. It includes 2-pin JST connectors to connect batteries in series, supplying a voltage of 7.4 V, and a 3-pin JST connector to distribute a 3.3 V power supply. The voltage regulation stage uses 5V and 3.3V AMS1117 regulators in module form. Control of the 6 V Pololu High Power (HP) Metal Microgearmotor DC motor is managed by the TB6612FNG integrated circuit, an H-bridge driver. This controller receives PWM signals from the Raspberry Pi Pico and regulates the current supply to the motor, which will activate the release mechanism. The MPU9250 module will be located externally on the housing cover to prevent interference and measurement errors. Additionally, the BME280 is included via a JST connector, which will be housed in the battery compartment on the top.

2.3.2 PCB2

Meanwhile, this PCB is in charge of managing the connectivity and communication of the sensors and wireless transmission modules. As seen in Figure 5b, the PCB has small strategic cuts to allow the passage of cables from the JST connectors to the external modules. Among these modules is the 9-degree-of-freedom MPU9250 inertial measurement unit (IMU), which is not mounted directly on the PCB, but on top of the CanSat. This location was chosen to minimize electromagnetic interference and ensure accurate magnetometer measurements. On the other hand, the XBee and GPS modules are integrated on the same PCB, but located on opposite layers to optimize the design. The XBee module operates at a frequency of 2.4 GHz, while the GPS module used is the SparkFun Breakout SAM-M8Q, chosen for its higher accuracy in short-range distance measurements. This is crucial for calculating the distance between the two parts of the CanSat using the Haversine formula.

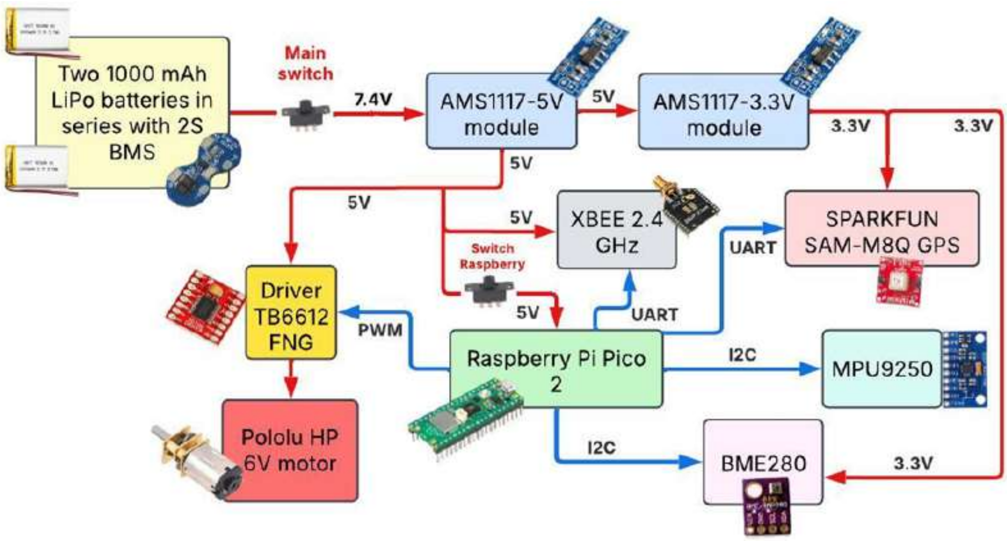
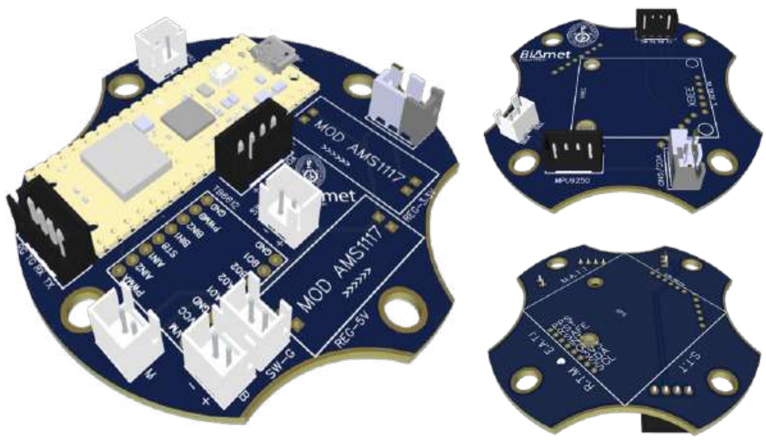
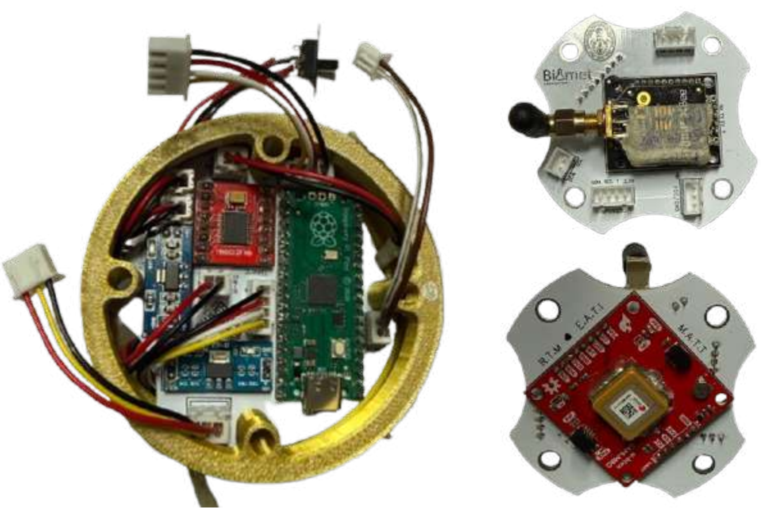


Figure 4: Top circuit: Electrical and electronic design



(a) (b)

Figure 5: Upper part of the CanSat: a) PCB 1 and b) PCB 2



(a) (b)

Figure 6: upper part of the CanSat manufactured: a) PCB1 and b) PCB2.

2.4 Lower part of the CanSat

2.4.1 PCB1

The same layout is followed as the previous diagram (Figure 5), where this PCB is dedicated to the microcontroller, which in this case is still the Raspberry Pi Pico, along with the 5V and 3.3V voltage regulator modules.

2.4.2 PCB2

It is responsible for managing data storage, communication, and data acquisition within the system. For data storage, a microSD module was used, along with the BME280 sensor, which was tasked with collecting data on atmospheric variables such as pressure, temperature, and humidity, and transmitting this data to the ground station—a critical requirement for the primary mission. Data transmission is handled by the same XBee module, operating at 2.4 GHz. In addition to this module, the SparkFun GPS module (SAM-M8Q) is also used.

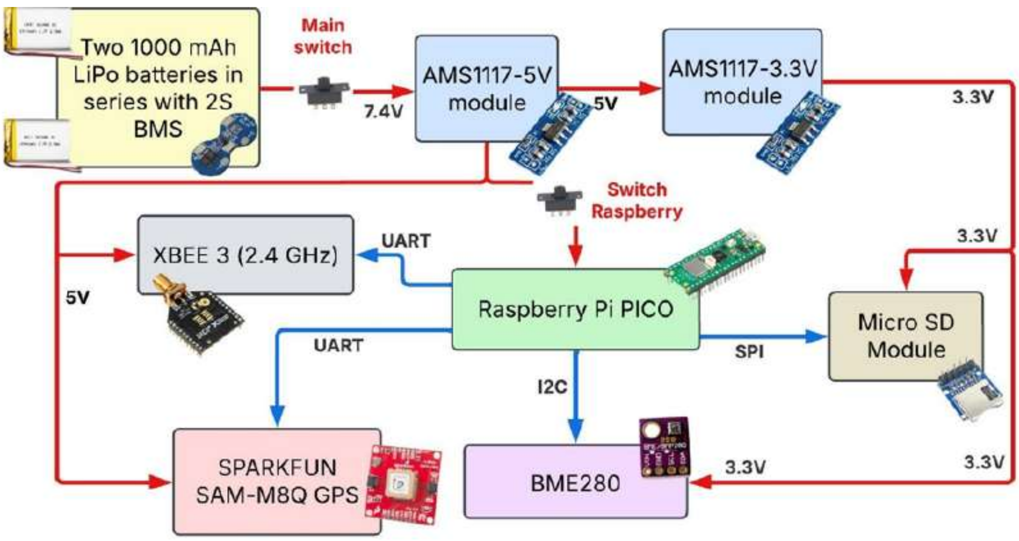
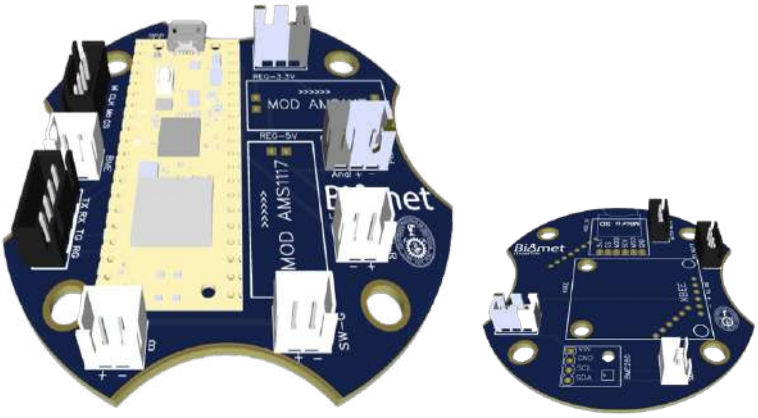


Figure 7: Bottom circuit: Electrical and electronic design



(a) (b)

Figure 8: Lower part of the CanSat: a) PCB 1 and b) PCB 2.

(a) (b)

Figure 9: Lower part of the CanSat manufactured: a) PCB1 and b) PCB2.

2.5 Mechanical system

2.6 Structre

El CanSat se asemeja a una estructura cilíndrica, lo que reduce la resistencia del aire y distribuye las tensiones de forma más uniforme en comparación con otras estructuras. Consta de varias piezas independientes, cuyo conjunto total tiene la forma de un cilindro de 200 mm de altura y 80 mm de diámetro. Para su diseño, todas las piezas se modelaron con el software Autodesk Inventor. La Figura 10 muestra la configuración mecánica completa del CanSat, modelada y ensamblada.

(a) (b)

Figure 10: General structure of the CanSat: a) modeled and b) printed.

2.6.1 Upper part

The upper section contains more modules and is responsible for fulfilling the secondary mission of altitude measurement without using a barometric sensor or altimeter. The BME280 sensor is used in conjunction with GPS altitude and longitude data to determine the relative distance between both parts. To ensure accurate and stable readings, the sensor was positioned away from the printed circuit board.

Additionally, an additional switch, specifically for the microcontroller, has been incorporated into both the top and bottom panels, in addition to the main switch. This switch allows the circuit to be isolated and the Raspberry Pi Pico to be directly connected to our laptop via a USB Type-C cable, facilitating testing without having to disassemble all the boards in the structure. This is done without requiring battery power. This disconnection is achieved through the VSYS pin.

The model shown above is shown in the following figure.

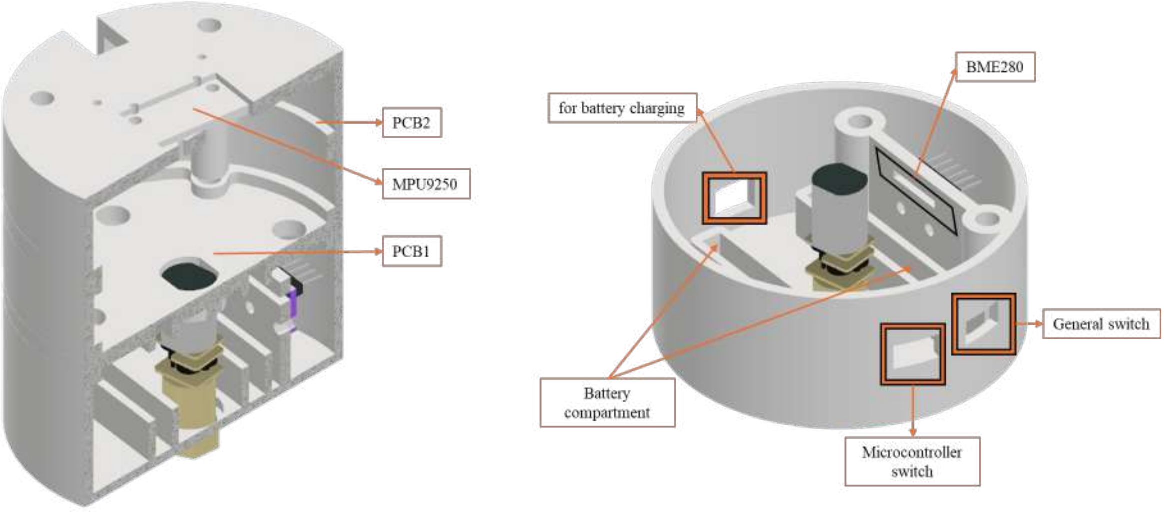


Figure 11: Model of the upper section

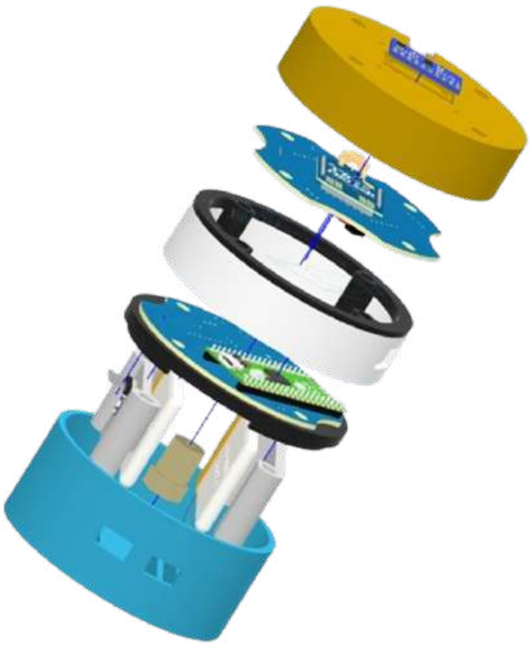


Figure 12: Model of the upper section

2.6.2 Lower part

This section of the CanSat is responsible for receiving data transmitted from the upper section, merging it with its own local data, and then retransmitting the essential variables to the ground station. The transmitted data includes only the variables necessary and useful for accomplishing the mission objectives. The batteries are housed in a protected compartment, which features small openings to facilitate better cooling.

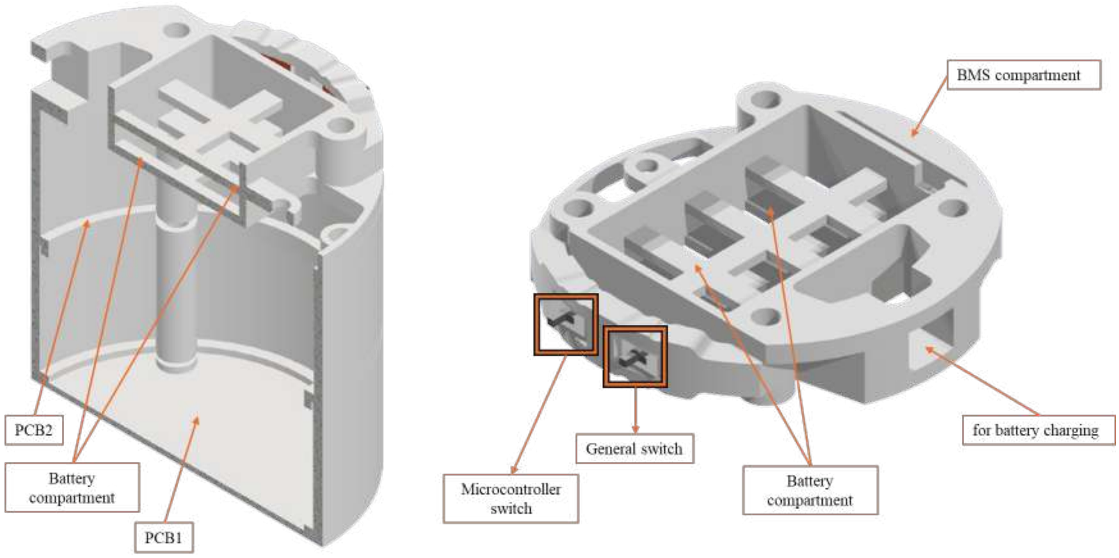


Figure 13: Model of the lower section

Figure 14: Model of the lower section

2.6.3 Mechanism (main mission)

This mechanism has three mobile elements that slide radially outwards, resting on a piece designed to house the hexagonal coupling (Figure 15). These elements have been called ”beams” due to their shape and analogous structural function, and make up the lower part of the CanSat. During operation, the DC motor rotates the piece that will house the hexagonal coupling. This rotation causes the ”beams” to move through the corresponding slots. To prevent premature movement of these elements, stops or retainers are incorporated, which act as locking mechanisms until the DC motor moves. Furthermore, a mounting system was designed for the bottom of the CanSat (Figure 15), which prevents the entire assembly from rotating with the motor, allowing only the central part with the hexagonal coupling to rotate.

The parachute will be positioned around the ”beams” in a compressed state (Figure 10b), ensuring that its storage does not interfere with deployment or the proper functioning of the separation system.

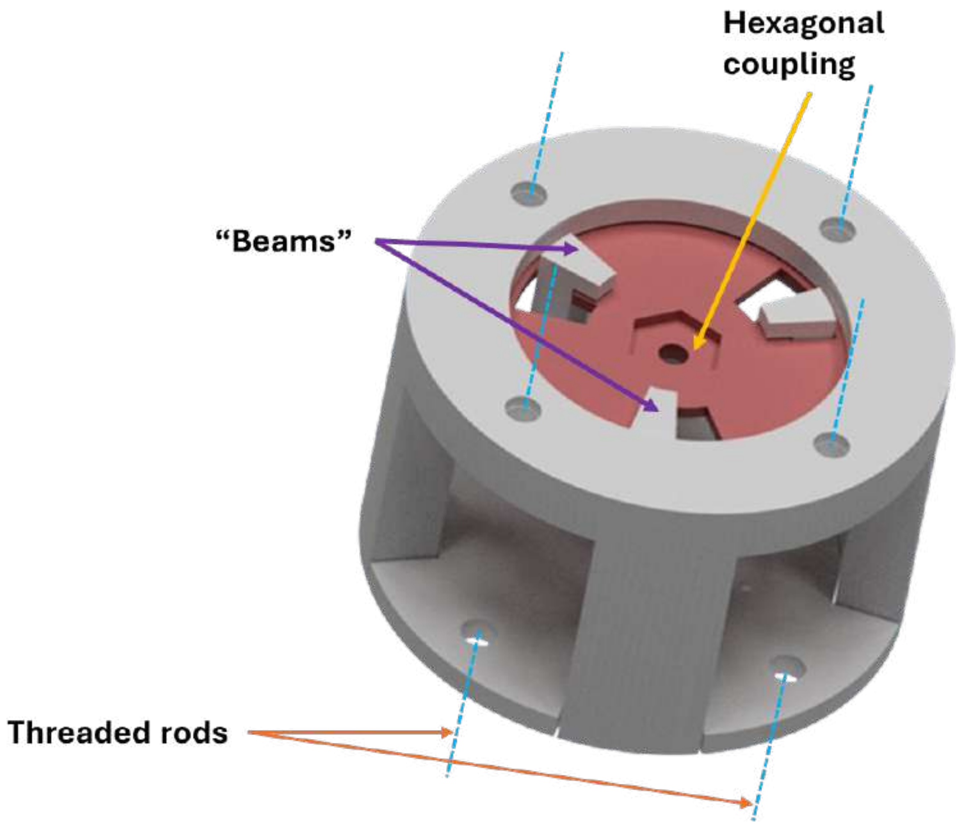


Figure 15: Second separation mechanism

2.6.4 Secondary mission: Measurement of height

The methodology for estimating height using IMU MPU9250 and Madgwick Filter can be summarize by:

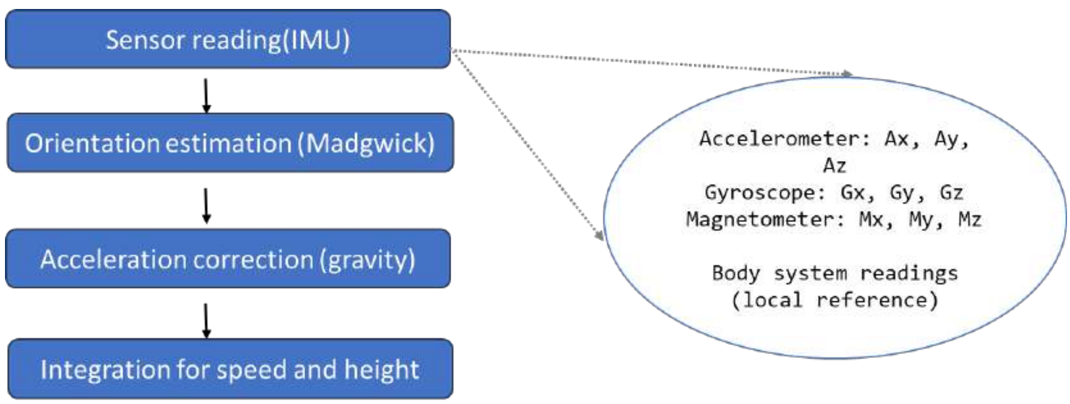


Figure 16: methodology for estimating height

Madgwick Filter

It fuses data from the accelerometer, gyroscope, and magnetometer to estimate the orientation of a 3D body and returns a quaternion $[q_0, q_1, q_2, q_3]$ that represents the orientation of the body in space.

Operation of the Madgwick filter

1. **Estimate from the gyroscope:** (quaternion product between orientation and angular velocity)
$$\dot{q} = \frac{1}{2} q \otimes \omega$$
2. **Correction by absolute sensors (gradient descent):**
$$\dot{q} = \frac{1}{2} q \otimes \omega - \beta \nabla f$$

Where:

- ω: angular velocity as a quaternion
- ∇f: gradient of the orientation error
- β: correction coefficient (balance between gyroscope and absolute sensors)

Calculating beta in the code:

```
self.GyroMeasError = math.pi * (40.0 / 180.0)
# Gyroscope measurement error in rads/s (start at 40 deg/s)

self.beta = math.sqrt(3.0/4.0) * self.GyroMeasError
```

Acceleration correction with quaternions

The accelerometer measures:

- The acceleration of actual motion
- The acceleration due to gravity
- In addition, it is in the frame of the (rotated) body

Solution:

1. Rotate the acceleration vector to the inertial frame:
$$\vec{a}_{\text{inercial}} = q \cdot \vec{a}_{\text{body}} \cdot q^*$$
2. Extract vertical component (global z-axis):
$$a_z^{\text{global}} = \text{componente z de } \vec{a}_{\text{inercial}}$$
3. Correct the acceleration by subtracting gravity:
$$a_z^{\text{corr}} = a_z^{\text{global}} - g$$

Numerical integration to estimate height

From basic physics:
$$a(t) = \frac{dv}{dt}, \qquad v(t) = \frac{dh}{dt}$$

We use discrete integration (Euler):

1. Vertical speed:
$$v_z(t + \Delta t) = v_z(t) + a_z^{\text{corr}}(t) \cdot \Delta t$$
2. Relative height:
$$h(t + \Delta t) = h(t) + v_z(t) \cdot \Delta t$$

2.7 Descent

2.7.1 Parachute design

It was necessary to perform an analysis of the projected surface area required for the parachute's design and manufacturing. For this analysis, we estimated the total weight of the CanSat to be 700 g. The weight distribution between the upper and lower sections of the CanSat was estimated to be 54.3% and 45.7%, respectively. Based on this estimate, the upper section weighs 380 g and the lower section 320 g. To calculate the projected surface area of the main parachute, we used the total weight of the CanSat, which is 700 g. This was done using the following equation:

$$v_\infty = \sqrt{\frac{2mg}{\rho A C_d}} \tag{1}$$

Obtenemos:

- Projected area for the main parachute: 0.2073 m^2 (to have a terminal velocity of 4.5 m/s)
- Projected area for the secondary parachute: 0.1123 m^2 (to have a terminal velocity of 5.5 m/s).

These values provide the necessary parameters for designing the parachutes, ensuring a controlled and stable descent for both stages of the CanSat system. By calculating the surface area, we can determine the diameter and radius of each parachute. For the main parachute, the calculated diameter was 51.5 cm, while for the secondary parachute it was 37.9 cm. To generate the parachute sections, we use the software Parachute Gore DXF Generator. The most important parameters for the design are:

- Diameter
- Spill Hole Diameter
- Number of Gores
- Chute Profile

2.7.2 Materials and manufacturing

Selected Materials:

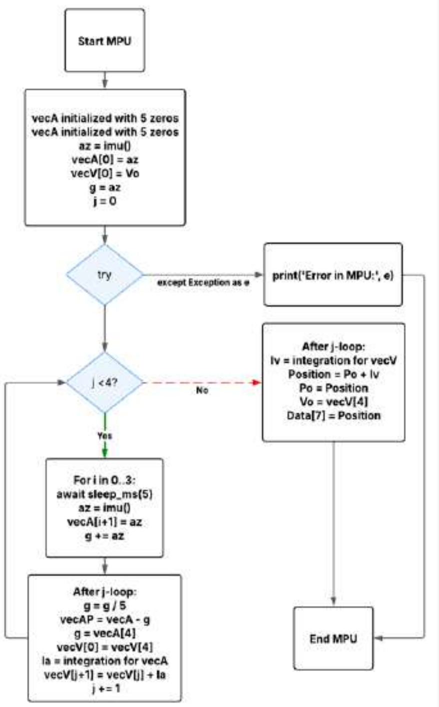
- **Ripstop nylon:** A lightweight, tear-resistant fabric used for the canopy of both the main and reserve parachutes. Its mesh structure prevents small tears from spreading.
- **High-strength polyester thread:** Used in all seams and reinforcements to ensure mechanical reliability under dynamic loads.
- **Braided nylon cord:** Used for the suspension lines due to its combination of strength, flexibility, and abrasion resistance.

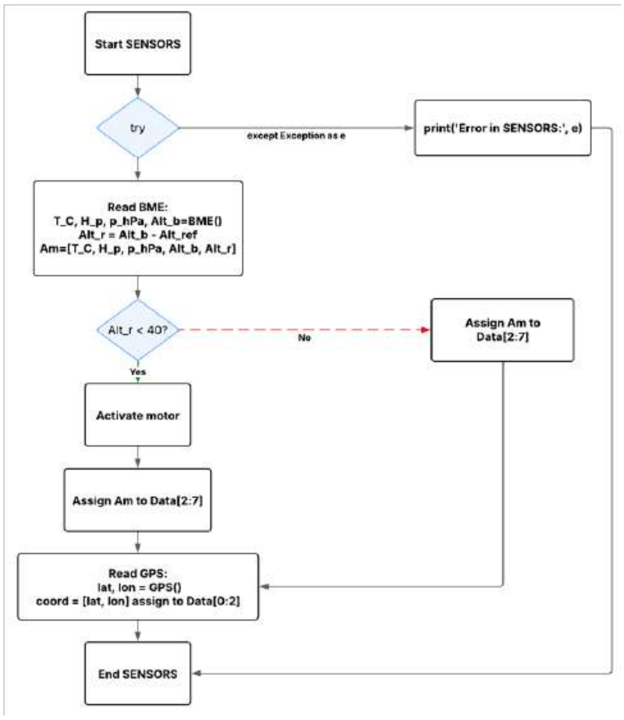
Assembly Process:

1. **Fabric cutting:** Using pre-calculated templates based on the parachute design, the ripstop nylon was precisely cut with a rotary cutter to maintain consistent edges and prevent fraying.
2. **Sewing the panels and reinforcements:** The cut fabric panels were sewn together with a zigzag stitch to provide flexibility and distribute stress evenly. Reinforcements were added at each suspension point with double stitching to reduce stress concentration.
3. **Integration of the suspension lines:** The suspension lines were cut to the required length and sewn to the reinforced anchor points on the canopy. All lines were connected using a tensioner to ensure even load distribution. The opposite ends of the lines were grouped together and connected to a central harness that attaches to the CanSat body. Figure 17 shows the final result.

Figure 17: From left to right, the secondary and main parachutes.

2.8 Communication





3. Launch Results

There was a problem with the separation mechanism, resulting in a failed separation. Furthermore, the secondary mission of measuring the distance between the two objects, which was planned to be done using GPS data, also failed. This was due to a last-minute malfunction of the GPS system, which prevented it from receiving the necessary data. Without this data, which was essential for using the haversine formula, it was impossible to calculate the distance between the two objects. The measurements of atmospheric variables taken by the upper part of the CanSat are shown below, including temperature, pressure, altitude, and relative humidity:

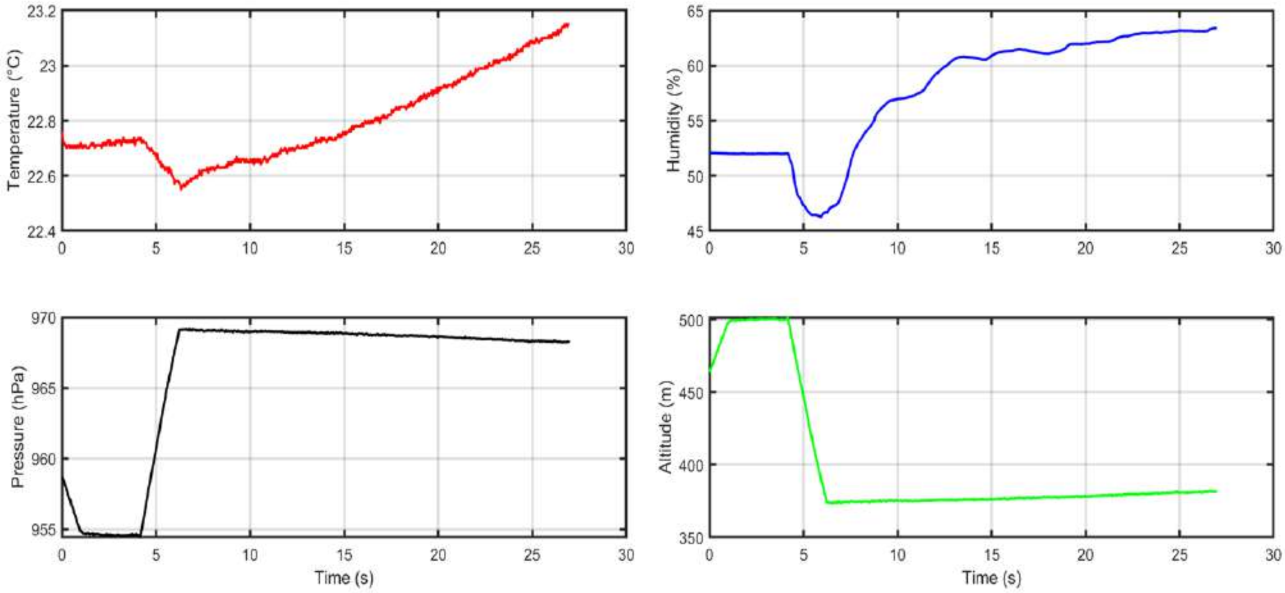


Figure 18: Measurement of atmospheric variables.

To measure the altitude relative to the launch point, the drone will be lifted from the container.

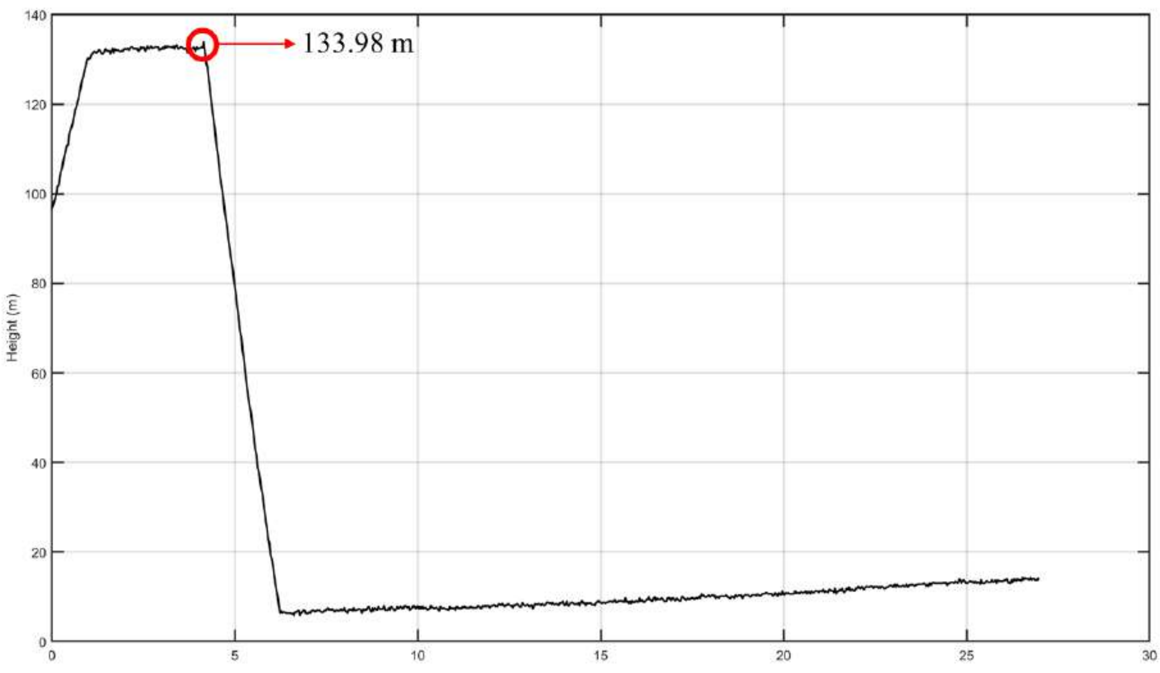


Figure 19: Measurement of heigth.

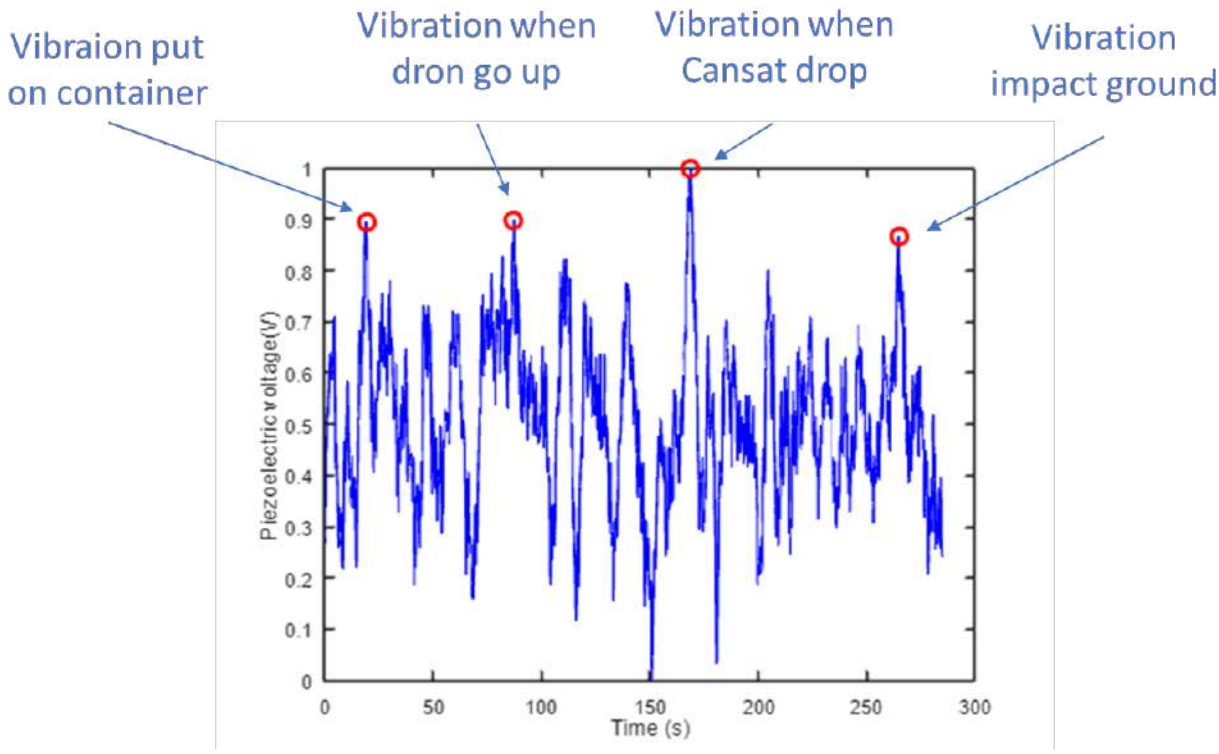


Figure 20: Measurement of vibration.