Critical Design Review

(CDR)

Peralta

Piarista Gimnázium

Budapest

17.02.2025.

Video link:

https://youtu.be/fpb1mMZZPKc?si=yaXNQRB7u6nggMrV

Table of contents

1. INTRODUCTION

1.1. Introduction of the team

We are studying at the Budapest Piarist High School in grade 12, in both A and B classes. We work completely independently, with a mentor who reviews and checks our work and helps us if we get stuck or have difficulties or if we have questions. We try to divide the work so that everyone does what they are good at or interested in, considering who has the time.

- Ákos Csányi: return system, logo design; 30 hours
- Barnabás Fazekas-Szűcs: media content, documentation, 20 hours
- Áron Kovács: electronics, software, 3D designs; 300 hours
- Bence Költő: 3D design, animations; 30 hours
- Péter Siklósi: data analysis, mathematical optimization; 20 hours
- Bence Márton Bolgár: mentor of our team.

Our Cansat team's name is Peralta, in honour of the founder of our high school St. Joseph of Calasanz. He was born in Peralta de la Sal in 1557, and he had an outstandingly strong calling for educating the poor, thus the Peralta name symbolises dedication to continuous learning and innovation.

1.2. Mission objectives

The secondary mission of our CanSat project is to investigate aerodynamic resistance during descent by analysing the shape factor of the parachute and evaluating the accuracy of general drag equations at different velocity ranges. This study will provide insights into how various parachute designs influence descent characteristics, which is particularly relevant for aerospace applications such as payload recovery and controlled landings.

Key Measurements and Tests

Our team will collect data on multiple parameters to assess aerodynamic performance, including:

- Descent speed: Measured using an onboard accelerometer and barometric sensor.
- Parachute efficiency: Evaluated by comparing expected and actual descent rates.

- Drag coefficient calculations: Using real-time velocity and air density measurements to verify theoretical models.
- Stability analysis: Examining fluctuations in acceleration and rotation during descent to determine stability.
- Lateral deflection is taken into consideration, as it could presumably be caused by the airflows such as wind or thermic or turbulence.

Expected Outcomes

This mission aims to validate whether theoretical drag equations accurately predict the descent characteristics of small-scale payloads. Specifically, we expect to:

- Identify variations in drag coefficients based on parachute shape and descent velocity.
- Determine whether standard aerodynamic models need adjustments for low-mass, high-drag objects like CanSats.
- Provide empirical data that could aid in optimizing parachute designs for similar small payload recovery systems.

Mission Success Criteria

For the secondary mission to be considered successful, the following objectives must be met:

- Successful data transmission: The CanSat must record and send descent data in real time via LoRa communication.
- Accurate measurement of descent characteristics: Collected data should be sufficient for calculating drag coefficients.
- Validation of theoretical models: The comparison between experimental and predicted values should enable a meaningful evaluation of drag equations.
- Stable descent with recorded anomalies: If any unexpected behaviours occur, such as excessive oscillations or deviations from the expected path, they should be well-documented for analysis.

This research is valuable for small satellite and payload recovery applications, as it contributes to a better understanding of descent dynamics in atmospheric conditions. By evaluating theoretical and real-world aerodynamics, we aim to refine future designs for small-scale recovery systems.

2. CANSAT DESCRIPTION

2.1. Overview of the mission

The CanSat satellite designed by our team will be launched on a rocket to an altitude of approximately 1 km, where it will be ejected and descended using a parachute system. During descent, it will measure acceleration, altitude (via GPS and barometric pressure), and temperature. Our primary mission focuses on measuring and analysing temperature and pressure data.

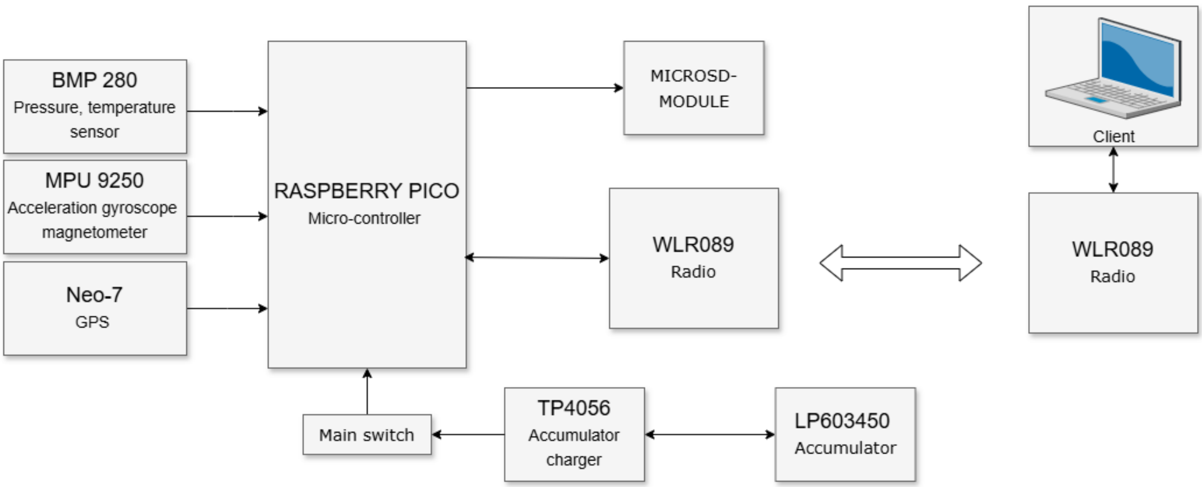
The secondary mission involves investigating aerodynamic drag, calculating the parachute’s drag coefficient, and evaluating the general equation's accuracy for different physical conditions.

All the collected data will be transmitted in real-time to the ground station via a LoRa module, while also being stored on an SD card for detailed post-flight analysis.

It will remain active for at least five hours after landing.

Critical Components and Systems:

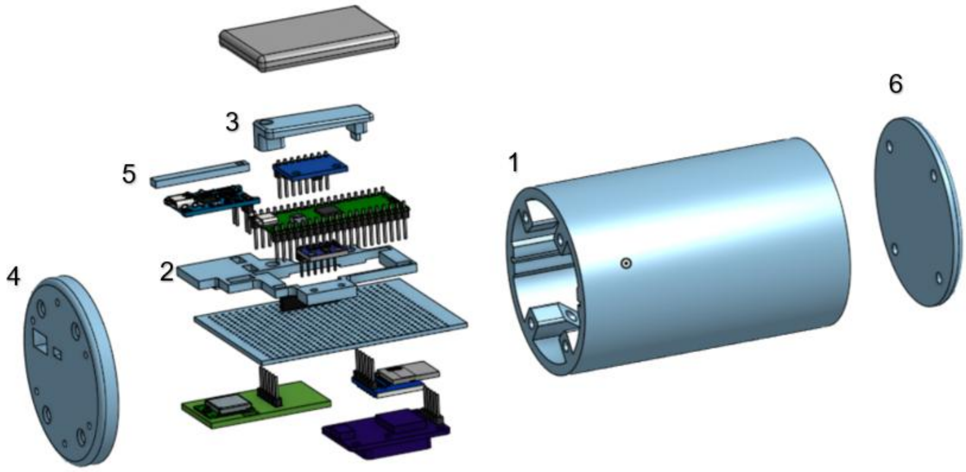
- **Sensors:** Accelerometer, (GPS module), barometric pressure sensor, and temperature sensor.
- **Communication System:** LoRa module for real-time data transmission.
- **Storage:** SD card for extended data recording.
- **Power System:** Battery and power management circuit.
- **Processing Unit:** Raspberry Pico for sensor data acquisition and processing.
- **Parachute:** hexagon shape with dyneema ropes.



1. Figure: Component diagram

2.2. Mechanical/structural design

The mechanical structure of the CanSat is primarily composed of **PLA, which is eco-friendly as it is made from renewable resources and biodegradable in industrial composting**. It also has a lower carbon footprint than traditional plastics. PLA is used for the cylindrical outer shell, internal supports, and module holders. The **rails** inside the cylinder ensure a **secure fit for the PCB**, preventing movement while allowing easy insertion and removal. The cylinder wall size is 4mm and its 90% filled to provide a little flexibility.



2. Figure: Onshape assembly

Component List and Purpose

Component	Purpose
(1) cylindrical PLA structure	Protects against external influences, as an outer frame
(2) custom PLA bracket	Fixes modules, also functions as a connector to the removable PLA component
(3) removable PLA component	Fixes the Motion Detect sensor to PCB
(4) upper lid	Connects the parachute to the outer frame
(5) main switch actuator	Provides power on/off when assembled
(6) bottom lid	Primary protection upon landing

Component Placement and Fixing

The **PCB** is housed inside a **cylindrical PLA structure (1)**, sliding in via a dedicated **rail system** for easy insertion. The rail stops before reaching the bottom, preventing unintended slippage.

On **top of the PCB**, the **Raspberry Pi Pico, battery charging module, temperature and pressure sensor, and main power switch** are secured using a **custom PLA bracket (2) and hot glue**, with elements directly **soldered to the PCB**. A **removable PLA component (3)** holds the **Motion Tracking Device** (MPU9520 – accelerometer, gyroscope, and magnetometer), securely screwed onto the **custom PLA bracket**, ensuring stability while allowing easy replacement if needed.

Underneath the PCB, **GPS, LoRa, and SD card writer modules** are fixed using **hot glue and soldering** and separated with **foam padding** to prevent interference and short circuits.

Electrical connections between module pins use **thin wire threaded through pads**, minimizing excess soldering and keeping wiring compact and organized.

The **upper section** is closed with a **6mm thick PLA lid (4)**, secured with heat-sert inserts and four **3mm metric screws**. The lid contains:

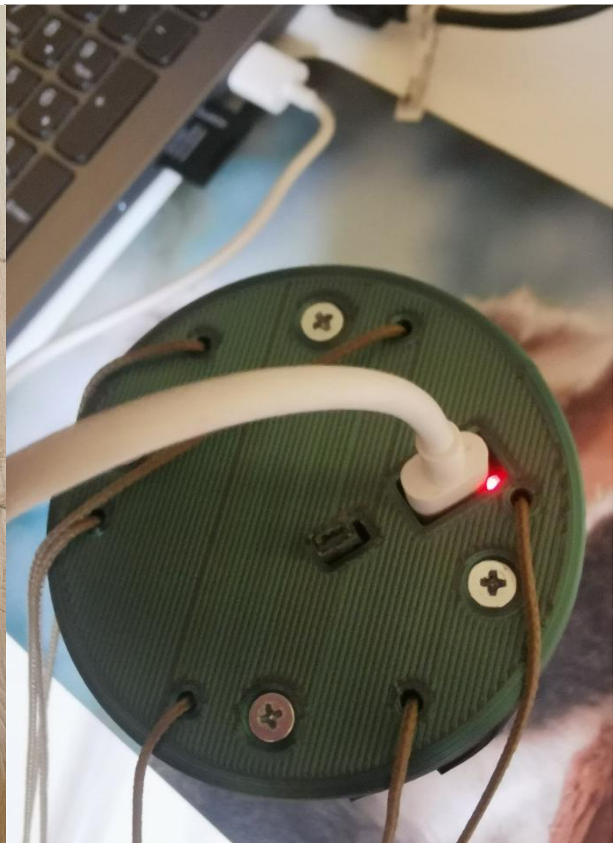
- **Six holes** guiding the **1.18mm Dyneema parachute cords**, secured with knots.
- A **Micro-USB port opening** for battery charging without disassembly.
- A **slot for the main switch actuator (5)**, which extends **1mm** when engaged but does not obstruct parachute deployment.

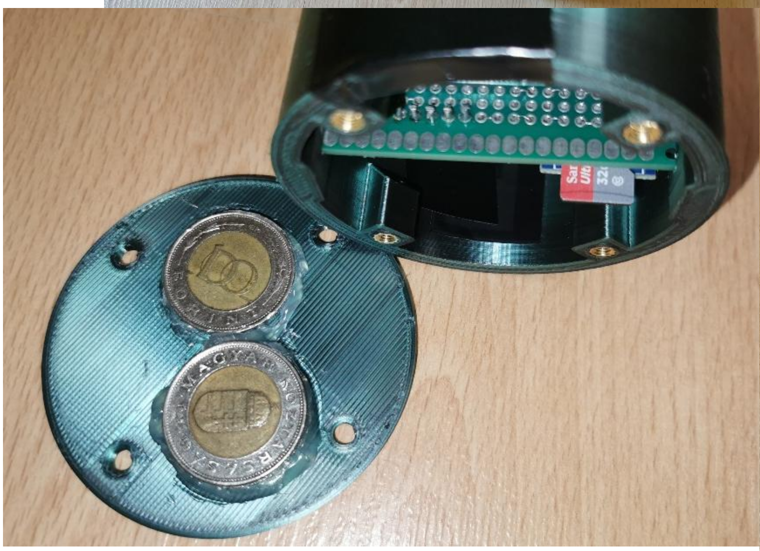
The **bottom lid (6)** is **4mm thick**, secured with heat-sert inserts and **3mm metric screws**. To ensure a flush surface, **small recesses are designed into the PLA structure at each screw point**, preventing the screws from protruding. Three **100 HUF coins** are attached as a **counterweight**, ensuring **stable descent and proper weight distribution**. Since the **PLA cylinder and covers** are the most fragile components, **spare parts** are available for quick replacements and durability testing under harsher conditions.

Battery and Antenna Mounting

The **LiPo battery** is glued to the **inner cylinder wall**, positioned alongside two **100 HUF coins** for stability and weight balance. The **antenna** is mounted externally on the **cylinder's side** and connected via a **coaxial cable** to the LoRa module. The cable is aligned **perpendicular to the antenna** to reduce interference and optimize signal transmission. To ensure maximum **communication range**, metal components are strategically positioned away from the antenna.

Pictures





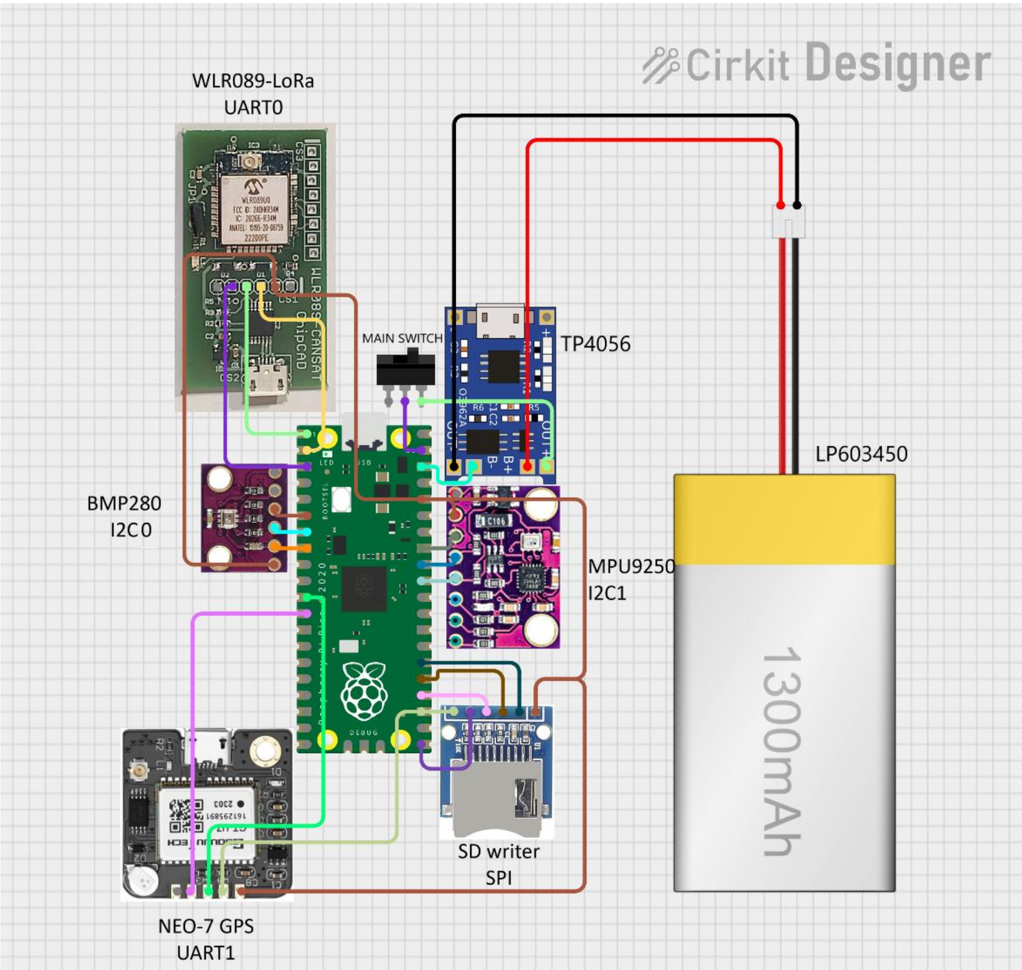
2.3. Electrical design

Electrical Interface of the CanSat

The CanSat system is designed with a compact and efficient electrical interface, ensuring seamless integration between the Raspberry Pi Pico microcontroller and the connected modules. All modules are directly soldered onto the PCB except for the MPU9250 and the Li-Po battery. The MPU9250 is connected via a pin header socket, secured with a removable PLA component and screws, while the battery connects through a wired interface to the TP4056 battery charger module.

The communication protocols between the modules and the **Raspberry Pi Pico** Central processing unit are as follows:

- **WRL089-LoRa Module**: UART0 communication,
- **NEO-7 GPS Module**: UART1 interface,
- **MPU9250 Motion Tracking Device (Accelerometer, Gyroscope, Magnetometer)**: custom I2C communication,
- **BMP280 (Temperature & Pressure Sensor)**: base I2C communication
- **MicroSD Writer**: SPI communication



3. Figure: Modul connections

The power system

- **TP4056 Battery Charger**: 3.7V Li-Po battery charging and protection circuit, output regulated by Raspberry Pi Pico,
- **LP603450 Li-Po Battery**: 1200mAh capacity, 3.7V nominal voltage.

RF Link Details

The LoRa radio module is responsible for bidirectional communication. The default settings for the RF link are:

- **Spreading Factor (SF):** 7
- **Bandwidth (BW):** 250 kHz
- **Transmit Power:** 15 dBm
- **Listen Before Talk:** Enabled
- **Frequency:** 868.1 MHz
- **Airtime:** 92.4 ms
- **Input Bytes:** 40 bytes per transmission

A tested range of 3 km has been successfully achieved between two bridges along the Danube, demonstrating reliable operation. *(See in the 3.2.3 Test section)*

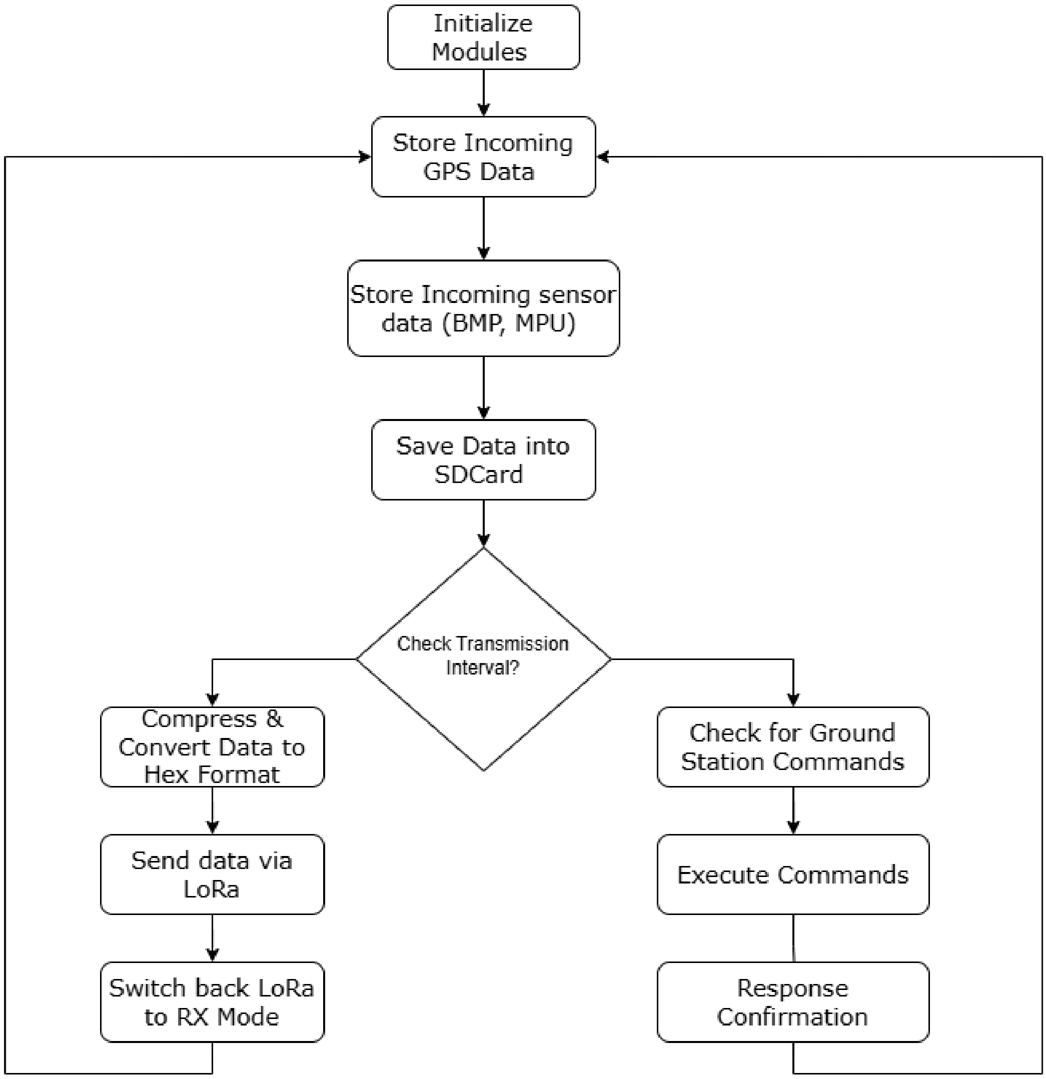
2.4. Software design

The CanSat software is designed to initialize all onboard modules, manage sensor data collection, store relevant information, and transmit the data to the ground station via LoRa communication. The software ensures error handling by logging errors and continuing operations if a failure occurs in one of the modules.

On-Board Data Handling (OBDH)

The software runs in a loop, each loop iteration takes **60 ms without LoRa** transmission and **200 ms with LoRa** transmission**,** performing the following tasks:

1. **Data Collection** – Checks for incoming GPS messages, extracts and stores important data, and reads sensor data (BMP280: temperature, pressure; MPU9250: accelerometer, gyroscope).
2. **Data Processing & Storage** – Formats and writes collected data to the SD.
3. **LoRa Transmission** – If the transmission interval has elapsed:
    - Compresses and converts data to hexadecimal format.
    - Switches LoRa to transmission mode and sends data to the ground station.
    - Returns LoRa to receive mode.
4. Otherwise, checks for and executes ground station commands.



4. Figure: Software Flow Diagram

Data Collection, Storage, and Transfer

The software collects and stores the following parameters in each data package:

- **Time** (System timestamp)
- **Temperature** (BMP280 sensor)
- **Pressure** (BMP280 sensor)
- **Acceleration** Gyroscope**,** magnetism (MPU9250)
- **MPU Temperature** (MPU9250)
- **GPS Data:** GPS Time, Latitude, Longitude, Altitude

Each data packet is 40 bytes in size, and with the default transmission interval of 500 ms, the estimated data rate in the ground station is calculated as:

$$data\,rate \;= \frac{package\ size}{transmission\ interval} = \frac{40}{0.5} = 80\,\frac{byte}{s}$$

It means that during the mission the time elapse is estimated 5 minutes, so the data transmitted will be 2.4 Kbytes.

The data storage size needed in the SD card:

$$data\,rate \;= \frac{package\ size}{average\ loop\ time} = \frac{40}{0.13} \approx 308\,\frac{byte}{s}$$

It means that from the power on to power off the time elapse is estimated 180 minutes, so the data storage should be 4.4 MB, and the max file size on the SD card is 4GB, therefore it is not going to be overflowed.

Data Compression and Transmission:

- Each parameter has a known range and precision, allowing for efficient compression.
- The raw values are normalized by subtracting the minimum possible value and dividing by the precision to obtain an integer.
- The integer values are converted to **hexadecimal** and formatted as a string.
- If necessary, leading zeros are added to maintain a constant packet size.

Example Compression:

- **Altitude:**
  - Min: 100, Max: 2000, Precision: 0.1
  - Measured Value: 342.4
  - Converted: (342.4 - 100) / 0.1 = 3424
  - Hexadecimal: D60
  - Transmitted as: 0D60 (padded for uniform size)

Ground Station Command Handling

The system receives ground station commands to adjust transmission settings, enable/disable LBT, reset LoRa, or enter sleep mode. An acknowledgment is sent for each executed command.

Development Environment and Programming Language

- **Development Environment:** VS Code with PlatformIO
- **Firmware:** Arduino-based
- **Libraries Used:** Wire.h, Adafruit_Sensor.h, Adafruit_BMP280.h, SPI.h, SD.h, lora.h, MPU9250.h

This software design ensures robust data collection, onboard processing, and reliable transmission to the ground station while maintaining efficiency and error tolerance.

2.5. Recovery system

Our recovery system consists of a 60 cm diameter hexagon shaped ripstop fabric parachute. The parachute is attached to the CanSat via 1.18mm diameter Dyneema cords. Key aspects of the design were:

- **Durability**: Both the Dyneema cords (200 kg tensile strength) and the ripstop fabric proved to withstand 20Gs of acceleration. Durability tests have been conducted to determine if our CanSat can meet the requirements. The testing can be seen in the spinning test video, in which we also measured the centripetal acceleration.
- **Descent rate**: For the descent rate our team aimed for a lower descent velocity for better measurement accuracy for the secondary mission. Several drop tests have been conducted to determine the descent rate of the CanSat. Three versions of the hexagonal parachutes were made, each with different diameters (30cm; 45cm; 60cm) and tested. Test results of the final version (60cm) were documented. Drop tests were conducted from a height of 13.5m and 19.5m. Tests were documented via video and descent time was established from it. Calculations for the descent velocity were also conducted. Results were 4.37 m/s at 13.5m height and 4.65 m/s at 19.5m height. Our team decided to make a 6cm diameter hole in the centre of the parachute to further increase the descent rate and stability of the CanSat. New drop tests were yet again conducted and documented. Our CanSat was thrown at approximately 5m and recorded on video. The recording was analysed by a program to determine the velocity. Velocity was established by the software between 6-7m/s. The estimated descent time is 130s.
- **Knots:** The knots are covered with heat-shrinkable tubes to prevent them from untying. The rope and the knots can withstand 50N load, as it can be seen in the video.
- **Folding**: We used an S shape parachute folding technique, which was also learnt in a dedicated CanSat training session. Its use is to ensure a fast and safe opening of our parachute. We used a cutout cylinder to determine whether the folded parachute will fit into the rocket. Results were positive: 3cm height in a 66mm diameter cylinder.

2.6. Ground station

Equipment and Devices

- **LoRa Module (WRL089-LoRa)**: The communication module for receiving data from the CanSat.
- **Antenna**: A **monopole antenna** with **2 dBi gain**, mounted externally on the protective enclosure and securely fastened to it to prevent damage.
- **Laptops**: Two laptops are used—one as the primary system and the other as a backup in case of power loss or technical failure.
- **Protective Enclosure**: The LoRa module is housed in a secure box, ensuring physical safety and easy antenna attachment.

Communication Channel

The communication between the LoRa module and the laptop is established via a **UART interface**, using a USB connection to ensure reliable data transfer.

Ground Station Software

The ground station software is developed in **Python** and runs on **VS Code**. It utilizes the following libraries: series, kivy, time, matpotlib, webbrowser, numpy.

Software Functionality

The ground station software features a **graphical user interface (GUI)** to enhance data readability and simplify command execution. Key functionalities include:

- **Live Data Display** – Shows the latest sensor values, optionally including signal strength (**RSSI**) and signal-to-noise ratio (**SNR**).
- **Data Monitoring** – Logs received data and displays a real-time acceleration graph (**Z-axis**).
- **Packet Reception** – Tracks expected data packets with a countdown timer and counts missed packets.
- **LoRa Control Commands** – Configures the LoRa module on the ground station (**radio rx 0, radio rxstop, radio get/set freq, pwr, sf, bw; sys reset**).
- **CanSat Control Commands** – Adjusts transmission settings (**sending speed (ms), set frequency (kHz), power, bandwidth, spreading factor**), enables/disables **Listen Before Talk (LBT: 0/1)**, resets the system (**reset: 0/1**), and enters sleep mode (**sleep (ms)**). CanSat confirms modifications, and the ground station updates its settings accordingly.

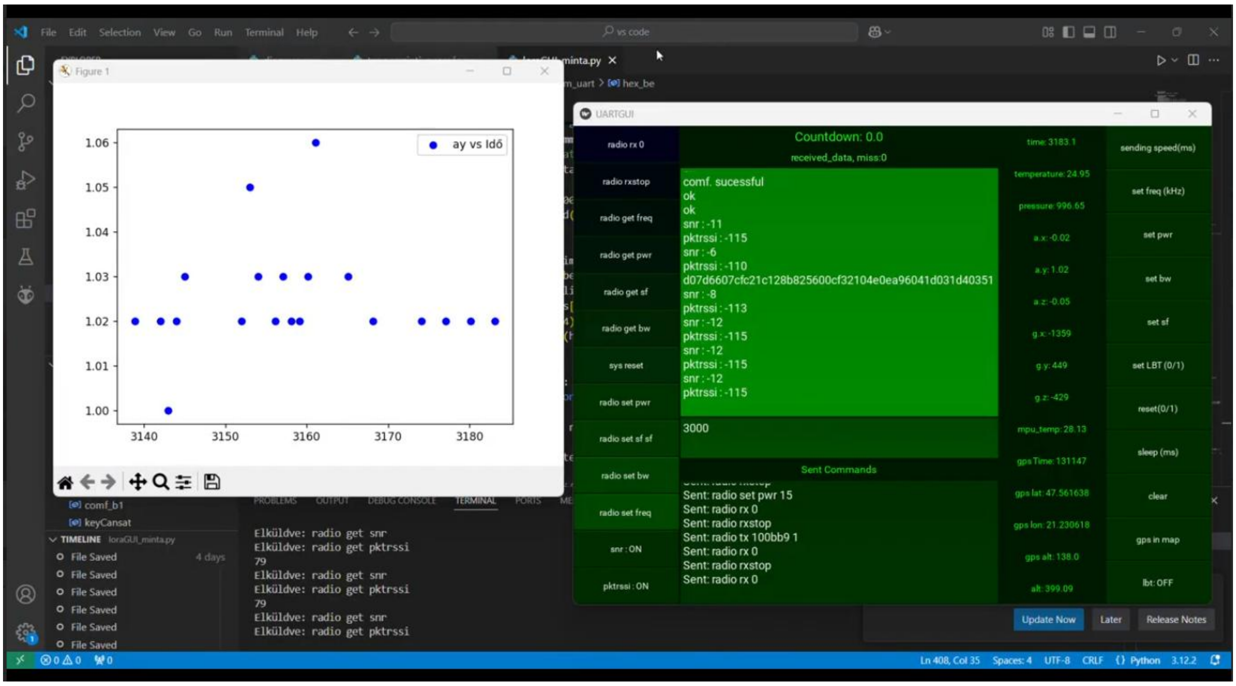
- **Navigation Assistance** – Generates a **Google Maps route** to the last known location of the device for its easy recovery.
- **Kalman Filtering** – Improves data accuracy and reliability by processing received data.

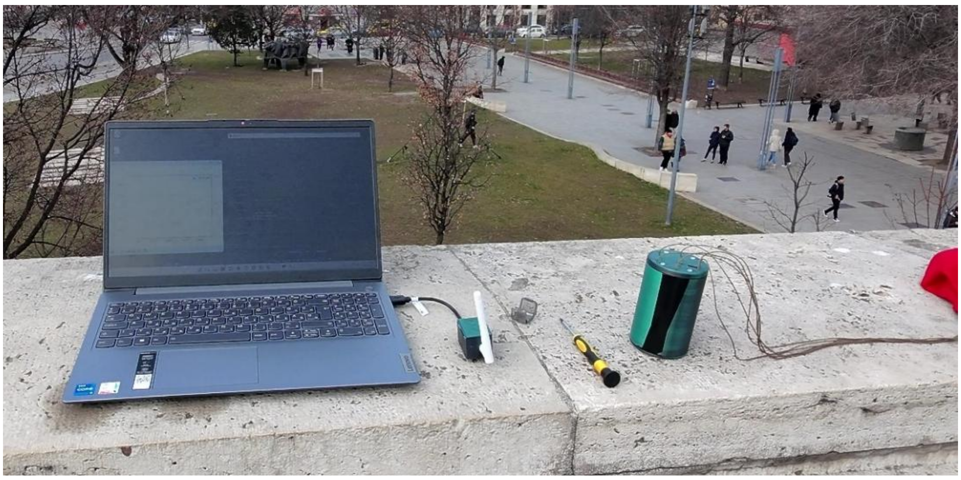
Preferred Radio Frequency Band

The ground station operates within the frequency bands that comply with **Hungarian radio amateur regulations** (NMHH Frequency Regulations).

- The **specific frequency** within the designated band will be provided by the jury before the event.
- The software is designed to allow **real-time frequency adjustments** on the event day, with a **default frequency of 868.1 MHz**

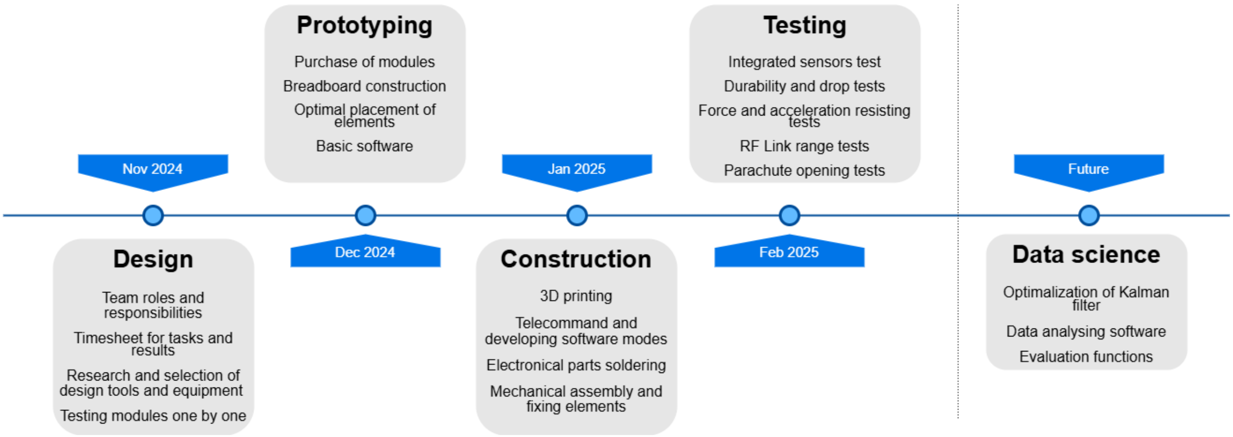
This comprehensive ground station setup ensures seamless communication, effective data management, and ease of operation during the CanSat mission.





3. PROJECT PLANNING

3.1. Time schedule of CanSat preparation[1]



5. Figure: CanSat Peralta Roadmap

3.2. Resource estimation

3.2.1. Budget

Item	Price per unit (HUF)	Price per unit (EUR)
NEO-7 GPS Module	3697,00	9,24
MPU9250	6344,00	15,86
BMP280	600,00	1,50
LoRa module (sponsored)	14000,00	35,00
MicroSD	5300,00	13,25
MicroSD reader	376,00	0,94
TP4056	253,00	0,63
LP603450 Li-Po Battery	3069,00	7,67
PCB	683,00	1,71
PLA (200g)	1200,00	3,00
Main switch	60,21	0,15
screws, glue, tin	500,00	1,25
parachute	3000,00	7,50
Total Cost	39082,21	97,71

[1] Detailed timesheet attached: https://docs.google.com/spreadsheets/d/1ztBNQEf_4Eot11a2LCCvqmSY-XNzn6z4/edit?usp=sharing&ouid=108060057419037051093&rtpof=true&sd=true

Total foreseen cost of our CanSat budget is approximately 100 EUR (calculated by 400HUF/EUR exchange rate), that is 5 times under the limit price.

3.2.2. External support

We really appreciate the support of the Hungarian National Cansat Competition Organisers and Lecturers, as well as the ESA educational sites, and last but not least Microchip/ChipCAD sponsor by whom the LoRa module was provided.

3.2.3. Tests

Our tests can fall in mainly two categories: the ones testing the structural integrity and the others testing the "brains", the software. Our structural tests include the testing of the landing, of the ropes of the parachute and the parachute itself. These tests were mainly successful, with our failures being important lessons, which led to strengthening the body of our CanSat. The later tests showed great results. The parachute tests were not that successful in the beginning, but we managed to make it work consistently. The software tests mainly include the testing of the signal strength, which was a big difficulty after the first test, but it later worked as expected at better conditions. We wrote test reports after every test we have done, where we went into greater detail of each test. We also documented every test, mostly by photos but we took videos of our tests as well. We analysed velocity with the video tracker.

videos:
https://drive.google.com/drive/folders/1LKsTGEyROW65qDUbngGWAkPPVLGnG8fs?usp=drive_link

test reports:
https://drive.google.com/drive/folders/1JDVZE1VqtYpuRg4YdJ_rl1u3SEswkFPL?usp=sharing

- Testing the structural integrity during landing
- Testing the strength of the cables for the parachute
- First test of the signal strength of Cansat
- Testing the capability of surviving the required accelerations
- Second test of the signal strength of the Cansat
- Final test

4. OUTREACH PROGRAMME

The approach to publicising and communicating the project:

In our project the main challenge was to make impression for people who are not related to space science and robotics. By sharing the interesting and funny moments of the experimenting we tried to reach as many people as we could. We started with designing the logo of our team which was inspired by the movie '2001: A Space Odyssey'. As soon as we finished with that, we could create our social media pages.

The existing social media platforms and how they will evolve:

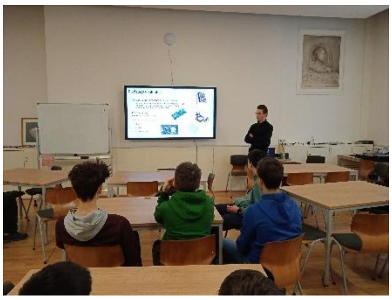
Our media team has recently been developing an Instagram page and a YouTube channel where the most thrilling moments and experiences can be found about the device. And of course we are planning to continue it, even after finishing the Cansat project we want to stay active on those platforms maybe as a team with another scheme or maybe just as a space news page. In our plans the main objective is to find a way of expanding our social media coverage to other platforms and to create a website one day. Some members of our team also introduced the device in school faculty groups. We are planning on to continue the demonstrations and displaying in the school media.

Summary list of all outreach activities carried out in the media:

- URL of the social media platforms:

Instagram: https://www.instagram.com/cansatperalta/
YT: https://www.youtube.com/channel/UCYZvyCv1MM4RvOqlzVD7JUQ

- Our team has designed a logo inspired by 2001: A Space Odyssey
- Áron Kovács, member of our team presented the completed satellite in the robotics study group of Piarista Gimnázium[2]
- Scheduled the making of an interview with the main school media source named Piarinsta



@CANSATPERALTA

[2] https://docs.google.com/presentation/d/1o4Dr-vixNcjqJM830ewfzXm6L5S0A8Mq/edit?usp=sharing&ouid=108060057419037051093&rtpof=true&sd=true

5. REQUIREMENTS

Characteristics	Quantity (unit)	Requirement	Eligible (Yes or No)
Height of the CanSat	111 mm	max. 115 mm	Yes
Mass of the CanSat	304 g	300-350 g	Yes
Diameter of the CanSat	64 mm	max 66 mm	Yes
Length of the recovery system	25 mm	max 45 mm	Yes
Flight time scheduled	130 s	~ 120 s	Yes
Calculated descent rate	7 m/s	5-12 m/s	Yes
Radio frequency used	868.1 MHz	~868 MHz	Yes
Power consumption	min. 5.6 hours	min. 5 hours	Yes
Total cost	100 EUR	max. 500 EUR	Yes

5.1.1. Preliminary energy budget

Power Budget

All components operate at 3.3V, regulated by the Raspberry Pi Pico. Below is the estimated power consumption:

Component	Voltage (V)	Current Draw (mA)	Power Consumption (mW)
Raspberry Pi Pico	3.3	20	66
WRL089-LoRa	3.3	120 (TX) / 10 (RX)	396 (TX) / 33 (RX)
NEO-7 GPS	3.3	45	149
MPU9250	3.3	3	10
BMP280 Sensor	3.3	0.5	1.65
MicroSD Writer	3.3	50	165

Battery Life Estimation:

- **Total Power Consumption (Peak, during TX):** ~787 mW
- **Total Power Consumption (Idle, during RX):** ~424 mW
- **Battery Capacity:** 1200mAh @ 3.7V → 4.44Wh
- **Estimated Operational Time:**
    - **Transmission Mode (~787mW):** ~5.6 hours
    - **Idle Mode (~424mW):** ~10.5 hours

The TP4056 battery charger ensures safe charging and discharging with built-in overcharge and over-discharge protection. The system is optimized for efficient power management, balancing operational performance with battery longevity.

On behalf of the team, I confirm that our CanSat meets all the requirements set out in the official guidelines for the 2025 Hungarian CanSat competition.

17.02.2025. Budapest

Bence Bolgár